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TECHNICAL MEMORANDUM

COMPUTED FIXED BEAM HORIZONTAL COVERAGE AS RELATED TO REDUNDANCY IN THE AN/SQS-26CX SONAR EQUIPMENT (U)

Contract NObsr-91039
Serial Number SS041-001;
Task 8100
TRACOR Project 22006

Submitted to

Chief, Bureau of Ships
Department of the Navy
Washington 25, D.C.

Attention: Code 1631

21 December 1964

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16 SS041

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17 SS041001

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TABLE OF CONTENTS

		Page
ABSTRACT		iii
LIST OF FIGURES		iv
LIST OF TABLES		vii
I.	INTRODUCTION	1
II.	RECEIVE	5
	A. Passive Mode	5
	1. Computations	5
	2. Analysis	7
	B. Active Modes	23
	1. A-Scan	23
	2. B-Scan	33
	C. Summary of Receive Modes	39
III.	TRANSMIT	41
	A. Surface Duct Modes	41
	1. Omnidirectional Transmission (ODT)	41
	2. Rotational Directional Transmission (RDT)	42
	B. Bottom Bounce Mode (BB)	48
	C. Convergence Zone Mode (CZ)	53
	D. Summary of Transmit Modes	58
IV.	COMBINATION TRANSMIT, RECEIVE AND SIGNAL PROCESSING	60
V.	SUMMARY AND CONCLUSIONS	63
LIST OF PERSONNEL		66
APPENDIX A - Note on Conditional Probability		A1
APPENDIX B - Passive Mode Beam Patterns		B1
APPENDIX C - Interrelated A-Scan Beam Patterns		C1

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ABSTRACT

Fixed beam horizontal coverage was assessed from beam patterns computed for arrays with assumed inoperative transducer elements, preamplifiers, power amplifiers, post amplifiers, and beam channels in the signal processor. The assessment was based primarily on changes in source level, receiving sensitivity and side lobe level.

A large part of this memorandum is concerned with a study of the statistical variation in the number of inoperatives from one array to another within one transducer, for various percentages of assumed inoperatives up to 50%.

It was concluded that the major receiving sensitivity change due to inoperatives could be compensated by overall gain adjustment, but that some statistical variation would be present. However, for a relatively small percentage of inoperatives, the variation is insignificant.

In the transmit mode, it was assumed that normal operation is just below cavitation, so that loss in source level due to inoperatives cannot be compensated by driving power adjustment. Thus, in the noise limited case, the decrease in source level is reflected in a loss of horizontal coverage.

The only detrimental effect of signal processing on the degradations is in the detector-averager, and then only for very small signal-to-noise ratio inputs. The correlator processors leave the changes unmodified or decreased, depending on the type of correlation and the input level.

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LIST OF FIGURES

		Page
1.	Beam Degradation Due to Random Inoperative Staves; Passive Reception	8
2.	Side Lobe Level for Transducers with Random Inoperative Staves; Passive Reception	9
3.	Passive Reception Pattern; 40% Random Inoperative Elements; 2.5kc	11
4.	Probability Distribution of Inoperative Staves in a Twelve-stave Array Selected at Random from a Complete Transducer with the Indicated Percentages of Staves Inoperative; Passive Reception	12
5.	Probability Distributions of Inoperative Staves and Elements in a Twelve-stave Array Selected at Random from Complete Transducers with 50% of Elements and 50% of Staves Inoperative; Passive Reception	14
6.	Theoretical Probability Distribution of the Variation in the Number of Inoperatives Between Two Randomly Selected Twelve-stave Arrays in a 50% (18/36) Inop.Trans.in Passive Reception	16
7.	Variations Between the Two Extreme Twelve-stave Arrays in 100 Hypothetical Transducers with 50% (18/36) Random Inoperative Staves; Passive Reception	17
8.	Variations Between the Two Extreme Twelve-stave Arrays in 100 Hypothetical Transducers with 30.6% (11/36) Random Inoperative Staves; Passive Reception	18
9.	Variations Between the Two Extreme Twenty-four-stave Arrays in 100 Hypothetical Transducers with 50% (36/72) Random Inoperative Staves; B-Scan	19
10.	Variations Between the Two Extreme Twelve-stave Arrays in 100 Hypothetical Transducers with 29.9% (86/288) Inoperative Elements; Passive Reception	20

LIST OF FIGURES CONT'D.

		Page
11.	Beam Degradation Due to Random Inoperative Elements; A-Scan Presentation; 0° Tilt Angle; 3.5KC	25
12.	Side Lobe Level for Transducers with Random Inoperative Elements or Staves; Horizontal Receive; 3.5KC	26
13.	Beam Degradation Due to Random Inoperative Staves - A-Scan Presentation; 0° Tilt Angle; 3.5KC	28
14.	A-Scan Presentation; 40% Random Inoperative Elements; 0° Tilt Angle; 3.5KC	30
15.	Beam Degradation Due to Random Inoperative Elements - B-Scan Presentation; 0° Tilt Angle; 3.5KC	34
16.	B-Scan Reception - 40% Random Inoperative Elements; 0° Tilt Angle; 3.5KC	36
17.	Beam Degradation Due to Random Inoperative Staves; B-Scan Presentation; 0° Tilt Angle; 3.5KC	38
18.	Side Lobe Level for Transducers with Random Inoperative Elements; Surface Duct-RDT; 3.5KC	44
19.	Effective Area Coverage Resulting from Source Level Degradation; Noise Limited Case	45
20.	Side Lobe Level for Transducers with Random Inoperative Elements; Surface Duct-RDT; 3.5KC	47
21.	Degradation of 45° Bottom Bounce Transmission Beam Pattern with Random Inoperative Elements; 30° Tilt Angle; 3.5KC	49
22.	Profile of Total Beam Pattern Valley Width for Different Levels of Degradation; Bottom Bounce Transmission; 45° Beam Width; 30° Tilt Angle; 3.5KC	51
23.	Side Lobe Level for Transducers with Random Inoperative Elements; Bottom Bounce Transmission; 45° Beam; 30° Tilt Angle; 3.5KC	52
24.	Degradation of 120° Convergence Zone Transmission Beam with Random Inoperative Elements; 0° Tilt Angle; 3.5KC	55

LIST OF FIGURES CONT'D.

		Page
25.	Profile of Total Beam Pattern Valley Width for Different Levels of Degradation; Convergence Zone Transmission; 120° Beam Width; 0° Tilt Angle; 3.5KC.....	56
26.	Side Lobe Level for Transducers with Random Inoperative Elements - Convergence Zone Transmission; 120° Beam Width; 0° Tilt Angle; 3.5KC...	57
27.	Composite Curve - Gaussian Noise, Ideal Signals..	61

LIST OF TABLES

Page

Table 1. Statistical Results from a Nonparametric Analysis of Groups of Transducers with an assumed Percentage of Inactive Staves or Elements..... 22

Table 2. Degradations Associated with 12 Interrelated A-Scan Beams with 40% Randomly Located Inoperative Elements..... 31

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COMPUTED FIXED BEAM HORIZONTAL COVERAGE AS RELATED TO REDUNDANCY IN THE AN/SQS-26CX SONAR EQUIPMENT (U)

I. INTRODUCTION

The purpose of this Technical Memorandum is to assess, from computed beam patterns, some of the effects of redundant sub-assembly failures on fixed beam horizontal coverage in the AN/SQS-26 sonar equipments. The primary consideration is redundant failures in power amplifiers (one per transducer element), transducer elements, preamplifiers (element signals) and post amplifiers (stave signals), with the effects being assessed through signal processing. Non-redundant failures, such as failure in a fixed beam channel of the signal processing circuitry, are also considered and assessed in this memorandum.

Most of the computations used in this study have been reported[1,2] previously, but the salient features of those works are presented here, together with some additional computations, and the data are presented in a format more suitable for this particular problem.

The prior studies involved determination of the effects of assumed inoperative transducer elements, preamplifiers and power amplifiers on (1) source level, (2) directivity index, (3) side lobe level and (4) SSI bearing error. All transmit and receive modes were considered, and both vertical and horizontal patterns were computed. Most of the computations were for arrays with randomly located inoperative transducer elements, amplifiers or staves up to about 50% of the total, but some more systematic

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[1] "Some Redundancy Effects on AN/SQS-26 Performance (U)", TRACOR, Inc., Technical Memorandum, 9 September 1963, Contract NObsr-89265, TRACOR Document No. 63-233-C. (CONFIDENTIAL)

[2] "Some Computed Effects of Assumed Inoperative Transducer Staves on Beam Formation and SSI Performance in the AN/SQS-26 Sonar Equipment (U)," TRACOR, Inc., Tech. Note, 29 Jan. 1964, Contract NObsr-91039, TRACOR Document No. 63-285-C. (CONFIDENTIAL)

arrangements were also studied. No passive patterns were computed, and analysis of the computed patterns from the standpoint of horizontal coverage was not within the scope of that task. Therefore, features of the referenced works which affect horizontal coverage will be used here to supplement the present data in assessing horizontal coverage.

The beam pattern computations used in this study are based on the assumption of no transducer element interaction and also on the assumption that the array is comprised of constant pressure sources. It is realized that these assumptions are not precisely true, but the results using these time and cost saving approximations should be sufficiently accurate in the far-field to evaluate relative changes in the parameters of interest. The effects of tolerances on the transducer elements and preamplifier responses were also treated in a study[3] concurrent with this study and thus will not be discussed here.

An additional assumption for this study is that failures in the various amplifiers and transducer elements are independent and occur randomly in the system. That is, the subassemblies assumed to be inoperative were selected on a random basis.

The parameters used here in evaluating fixed beam horizontal coverage include source level, receiving sensitivity, and side lobe level in both transmit and receive, as well as the shape and structure of the wide beam transmit cases.

In order to avoid confusion later we will now define what is intended by the statements "a stave is inoperative" and "a stave subassembly is inoperative."

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[3]"Some Computed Effects of Phase and Amplitude Tolerances on Horizontal Beam Patterns of the AN/SQS-26 Sonar Equipment (U)," TRACOR, Inc., Technical Memorandum, Contract NObsr-91223, TRACOR Document No. 64-256-C. (CONFIDENTIAL)

Definitions:

Stave Assembly - (1) Composed of eight transducer elements, eight preamplifiers and one post amplifier, in receive.

or

(2) eight power amplifiers and eight transducer elements in transmit.

Stave Sub-assemblies - transducer elements, preamplifiers, power amplifiers and post amplifiers.

Inoperative stave (Transmit) - an inoperative stave assembly due to any combination of inoperative transducer elements or associated power amplifiers which form a vertical column of eight.

Inoperative stave (Receive)- an inoperative stave assembly

(1) due to an inoperative post amplifier

or

(2) due to any combination of inoperative transducer elements or associated preamplifiers which form a vertical column of eight.

In the interest of brevity, the term "inoperative element" in this report will mean an inoperative transducer element and/or the associated power amplifier in transmit, and an inoperative transducer element and/or the associated preamplifier in receive. The net effect of an "inoperative element" is that there is no output signal, either from the transducer element in transmit, or the preamplifier in receive, no matter which stave subassembly is defective.

Another point of clarification is the proper interpretation of the graphs contained in this report. All of the curves herein are based on the assumption of a known number of inoperatives. For example figure 4 gives the probability of x inoperative staves in an array selected at random when it is known that 50% of the total number of staves in the entire transducer are inoperative.

The assumption of a known number of inoperatives can be removed. For a more general discussion of this problem, see Appendix A.

Concern over actual probabilities of failure of the various assemblies in the AN/SQS-26 sonar equipment is beyond the scope of this memorandum. However, practical use of the information contained herein requires a knowledge of the actual failure rates in order to determine the statistical horizontal coverage as a function of time.

Some analytical work was performed on the problem of determining the variations in horizontal coverage which might be expected with various probabilities when it is given that a certain percent of the staves or element subassemblies are inoperative. The results confirm that, in general, the random failure assumption tends to keep the degradation in horizontal coverage somewhat uniform, with extreme variations being highly improbable.

The results are presented in the following three Sections: II. RECEIVE; III. TRANSMIT; AND IV. COMBINED TRANSMIT AND RECEIVE; with an additional Section V. SUMMARY AND CONCLUSIONS.

II. RECEIVE

A. Passive Mode

1. Computations

The passive mode employs 72 fixed beams, one formed at each 5° in azimuth. All of the beams are simultaneously formed from 36 stave signals emanating from every other stave out of the 72 staves used in the active modes. Beam forming is by the DIMUS technique and each beam is formed by 12 or 13 stave signals, depending upon the azimuthal location. The passband for passive reception is 1.5 to 2.5 kc, but in this study only the two end frequencies were used in computations.

Thirteen beam patterns were computed at each frequency for the 12 stave arrays, assuming inoperative staves to be in randomly selected locations in the array. It was assumed that, for practical purposes, the patterns for 13 stave arrays would not be significantly different. In the interest of minimizing the number of computations, inoperative stave cases were computed rather than inoperative element cases, since the effects of a certain percentage of inoperative staves is significantly worse than the same percentage of inoperative elements. In actual operation, there will probably be some of both inoperative.

Three of the arrays for which patterns were computed had two assumed inoperative staves; three had four assumed inoperative staves; and six arrays had six (half the total number) staves assumed inoperative. Beam patterns with all 12 staves operative were computed at both frequencies to provide reference standards. All of the passive patterns are included in this report as Appendix B.

The primary considerations in passive horizontal coverage are degradation of the main lobe in both sensitivity and shape, and degradation of side lobe level. Since the fixed beams are 5° apart, they normally overlap at about 2.5^{o} from the main lobe peaks. If a beam becomes inoperative, the main lobes

of the beams on either side intersect at about 5°. The computed degradations in the beams from the main lobe peak, at 2-1/2° and at 5° for the 13 arrays at 1.5 kc and 2.5 kc are shown in Figure 1. The degradation at the peak (0°) is essentially the decrease in sensitivity due to the assumed inoperative staves. The 2-1/2° curve indicates the level at which the main lobes would normally crossover, while the 5° curve shows the approximate crossover level where an entire beam is inoperative.

The absolute value of the degradation for a large percentage of inoperative staves is somewhat misleading, in that the master gain control could be adjusted to offset part of the degradation. The variation of the beam degradations in a particular case will determine just how much the gain can be increased. The expected range of these variations will be discussed below in part (2) of this section.

A significant variation in the degradation of the 5° point for the 2.5 kc cases can be seen in Figure 1. This is in contrast with the relatively small variation in the 1.5 kc cases. The difference is due primarily to the fact that the main lobe is much narrower at 2.5 kc than at 1.5 kc, so that the 5° point is on a rather steep portion of the main lobe in the former case. Hence a small variation in the main lobe shape can influence the 5° crossover point considerably. Thus the possibility does exist for a rather deep crossover point if a beam becomes inoperative at 2.5 kc and if additionally there are a large number of inoperative elements - although this is not a likely case. The width of such a "hole" in the horizontal coverage would be about 2° at - 5 dB, and changes only a few tenths of a degree with changes in the percentage of inoperative elements. Since this situation is worse at one end of the frequency band (2.5 kc), it is probably of no great concern in operation over the entire frequency band.

The other parameter of primary interest to horizontal coverage is side lobe level. Figure 2 is a plot of the

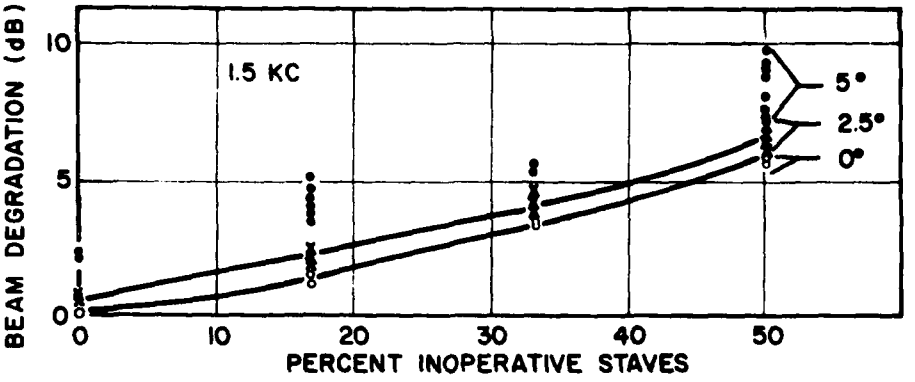
highest side lobe with respect to the main lobe peak for each case computed, at both frequencies. It is apparent that some of these side lobes are of such a high level that signals could be detected on them, yielding erroneous target bearing indications.

2. Analysis

In looking at the problem of fixed beam passive mode horizontal coverage, one is interested primarily in the variation in sensitivity around the azimuthal circle. If there were no variation, the over-all gain could simply be increased to offset the decreased sensitivity. However, in reality, there will be some distribution of inoperative elements or staves which is not precisely uniform, such that sensitivity variations will exist. It is of interest to investigate the range of the variations which might be expected.

The problem of determining the probability of some particular maximum variation in the number of inoperative elements (which is related to sensitivity as shown previously) between two different arrays in a transducer was attacked on two fronts. An attempt was made to theoretically derive the relevant probability distributions regarding the number of inoperative elements or staves in the various arrays of a transducer with a specified total number of inactive elements or staves. This attempt proved partially - though not completely - successful. Simultaneously, an empirical investigation was initiated by determining the disposition of inoperative staves in several hundred complete but hypothetical transducers with a fixed number of defectives. This data was then analyzed through nonparametric methods of statistics to place a confidence on the results obtained therefrom.

As a "typical" case likely to provide some "feeling" for the problem, a complete transducer of 36 staves with eight elements each was analyzed by randomly selecting the position of inoperative elements so that approximately 40% of the total were



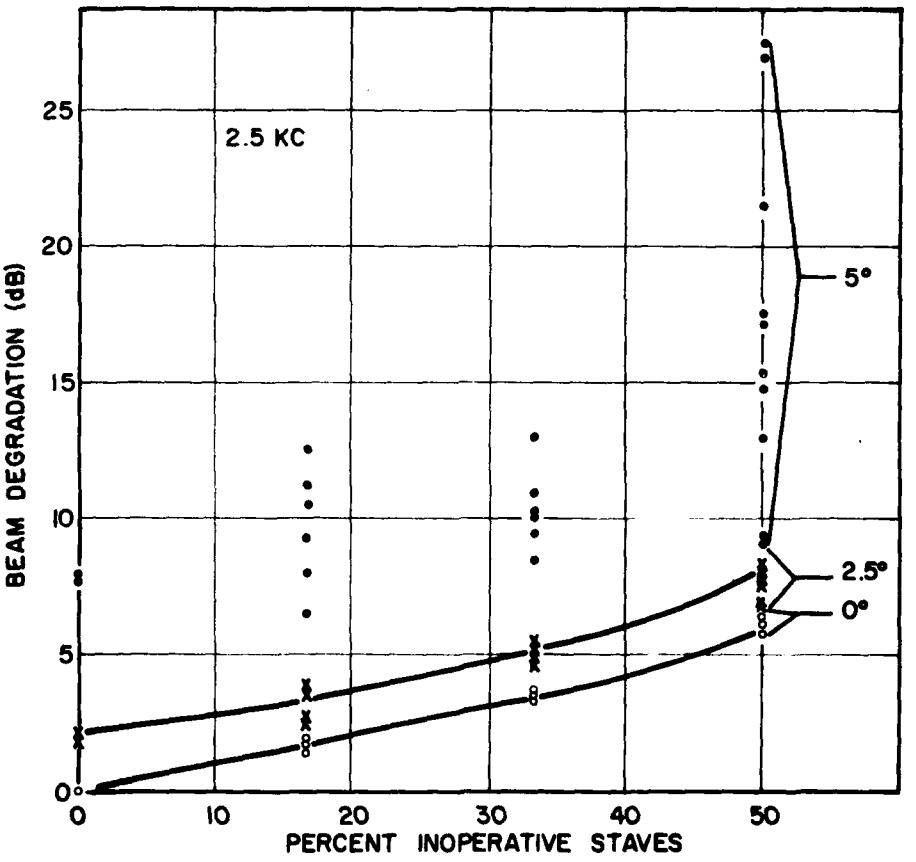


Fig. 1 - BEAM DEGRADATION DUE TO RANDOM INOPERATIVE STAVES; PASSIVE RECEPTION

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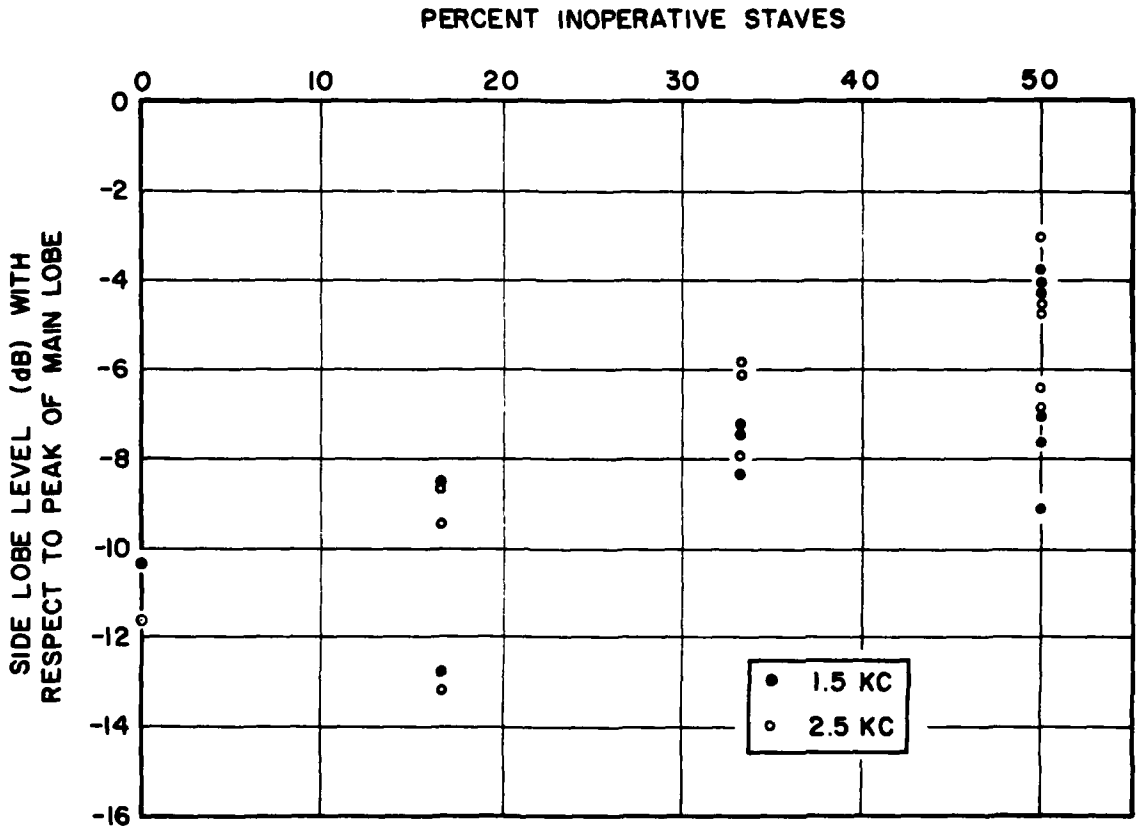

Fig. 2 - SIDE LOBE LEVEL FOR TRANSDUCERS WITH RANDOM INOPERATIVE STAVES; PASSIVE RECEPTION

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inoperative. This was done by associating each element with a sequence of equally probable random numbers composed of the numbers 0-9 and declaring that 0, 1, 2, and 3 would represent inoperative elements and that 4 thru 9 would represent operative elements. The number of inoperatives in each of the 72 arrays was determined by simple counting. The approximate degradations for each array were read from the curves of Figure 1 (2.5kc) and plotted on polar paper. Seventy-two separate major lobes were plotted down to the crossover points and are shown in Figure 3. One entire beam was assumed inoperative to show the amount and angular width of the degradation resulting from such an occurrence.

The variation in the peak sensitivity of the various arrays (exlcuding the inoperative beam) shown in Figure 3 is the significant factor and is about 2.5 dB. If this same hypothetical transducer were analyzed at the 1.5 kc frequency, the variation in the peak sensitivities would be unchanged, but the valleys between peaks, or places where a beam is missing, would be considerably less pronounced due to the wider major lobe at the lower frequency.

The initial theoretical result was the determination of the probability density distribution of the number of inoperative staves in an array of 12 staves, where the transducer from which the sample array was obtained has a specific percentage of inoperatives. The distributions were calculated for transducers with 18 staves (50%), 14 staves (38.9%), and 11 staves (30.6%) inoperative by using equation (9) in Appendix A and the results are shown in Figure 4. The interpretation of Figure 4 is as follows: In a large group of sonar equipments, each of which has 50% of the 36 staves inoperative, approximately 27-1/2% of the 12 stave arrays would have six inoperative staves. Whereas, in the same large group, theoretically only 0.0015% of the 12 stave arrays would have all of the staves inoperative. This probability is so small that one would practically never expect all of the

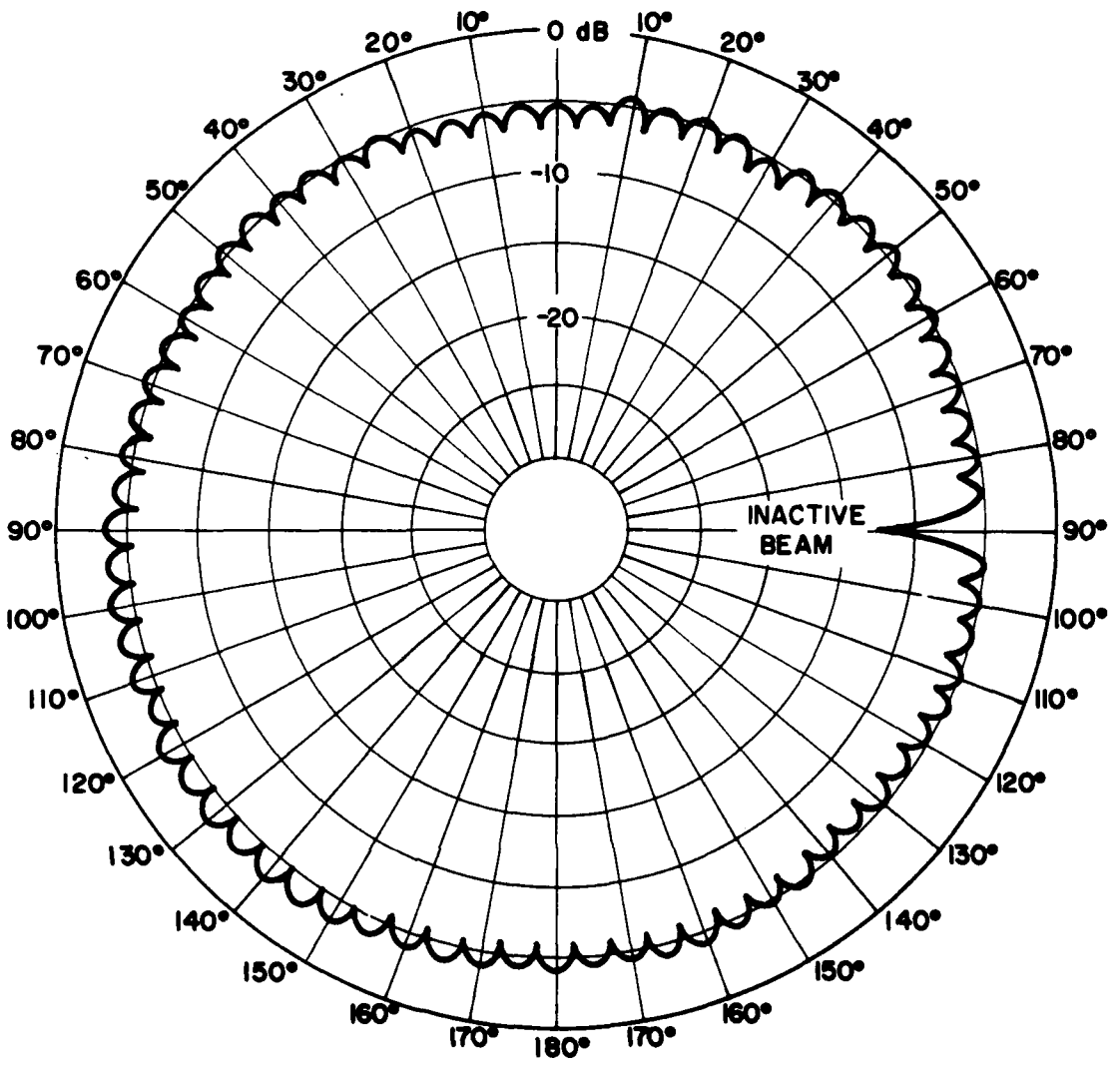

Fig. 3 - PASSIVE RECEPTION PATTERN; 40 % RANDOM INOPERATIVE ELEMENTS; 2.5 KC

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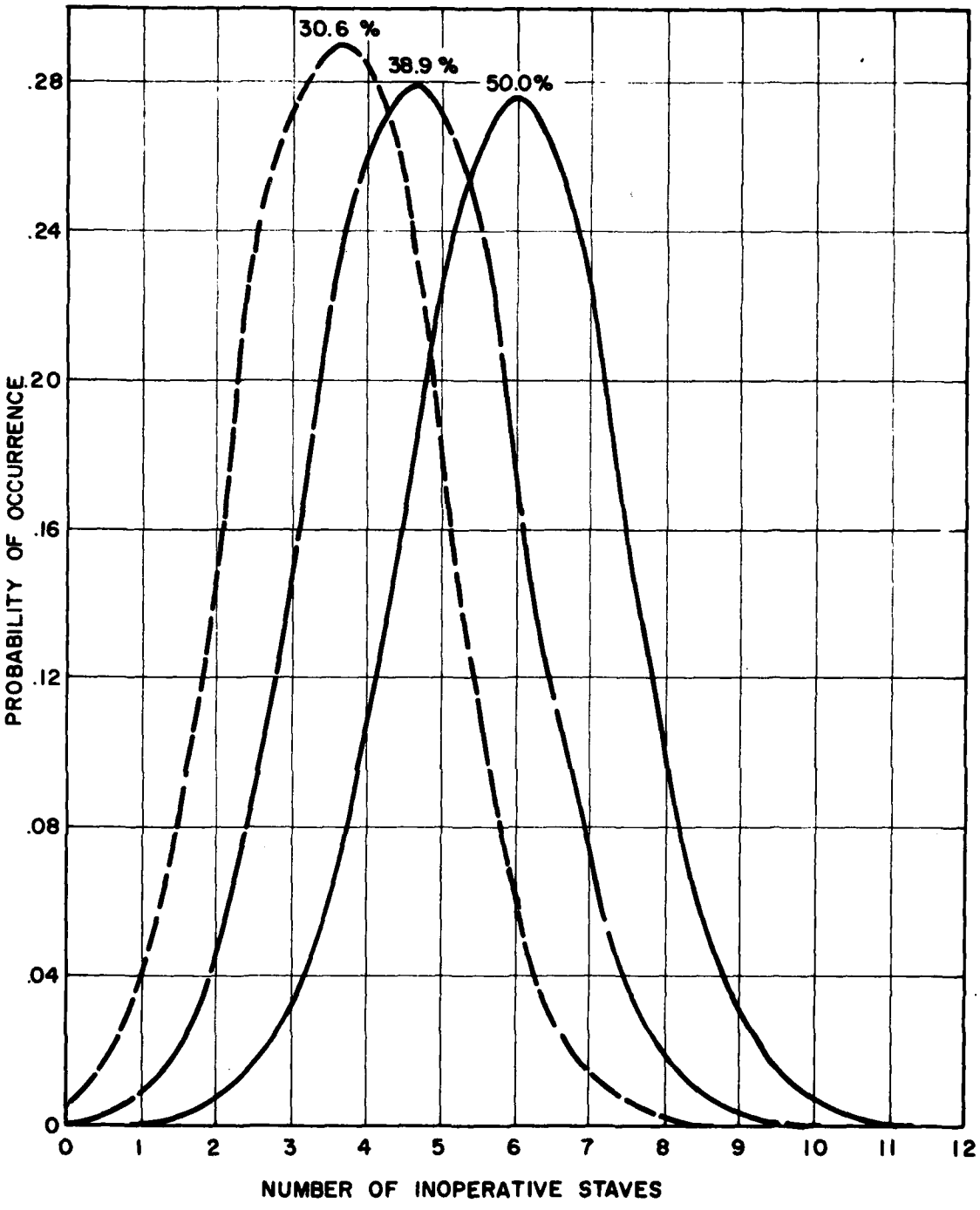

Fig. 4 - PROBABILITY DISTRIBUTION* OF INOPERATIVE STAVES IN A TWELVE-STAVE ARRAY - ARRAY SELECTED AT RANDOM FROM A COMPLETE TRANSDUCER WITH THE INDICATED PERCENTAGES OF STAVES INOPERATIVE; PASSIVE RECEPTION

*EQUATION 9 - APPENDIX A

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12 staves to be inoperative.

As stated previously, actual cases will involve both inoperative staves and elements, and it should be emphasized that the statistics for the two cases are significantly different. A plot of the probability density distribution for the case of inoperative elements is shown in Figure 5 along with the plot for 50% inoperative staves from Figure 4. The inoperative element curve is for the case in which a sample of 96 elements is obtained from a population of 288 elements of which half are randomly located inoperatives. The heights of the ordinates of the curves of Figure 5 represent the probability of occurrence of that particular number of inoperatives (elements or staves). For example, both curves indicate that if 50% of the total are inoperative, then in any array selected at random 50% inoperatives (6 staves or 48 elements) is the most likely, but that 4 inoperative staves is much more probable than the equivalent percentage of inoperative elements (32).

One can look at Figure 5 and get a rough intuitive feeling about the variation in the number of inoperatives in 36 interrelated arrays of 12 staves (or 96 elements) each. For example, in the 50% inoperative case the situation of one array with no elements or staves inoperative, or one with all inoperative in the same transducer would appear to be a highly improbable occurrence, since the ordinates at the end points of the curves of Figure 5 are essentially zero. Therefore one would rarely if ever, expect to observe these maximum variations. On the other hand, it looks reasonably probable that one might for example observe cases of three and nine inoperative staves in the same set of 36 arrays (i.e. in the same transducer).

The second theoretical development was the determination of the probability distribution of the variation in the number of inoperative staves between two 12-stave arrays which have been randomly selected from a transducer with a specified

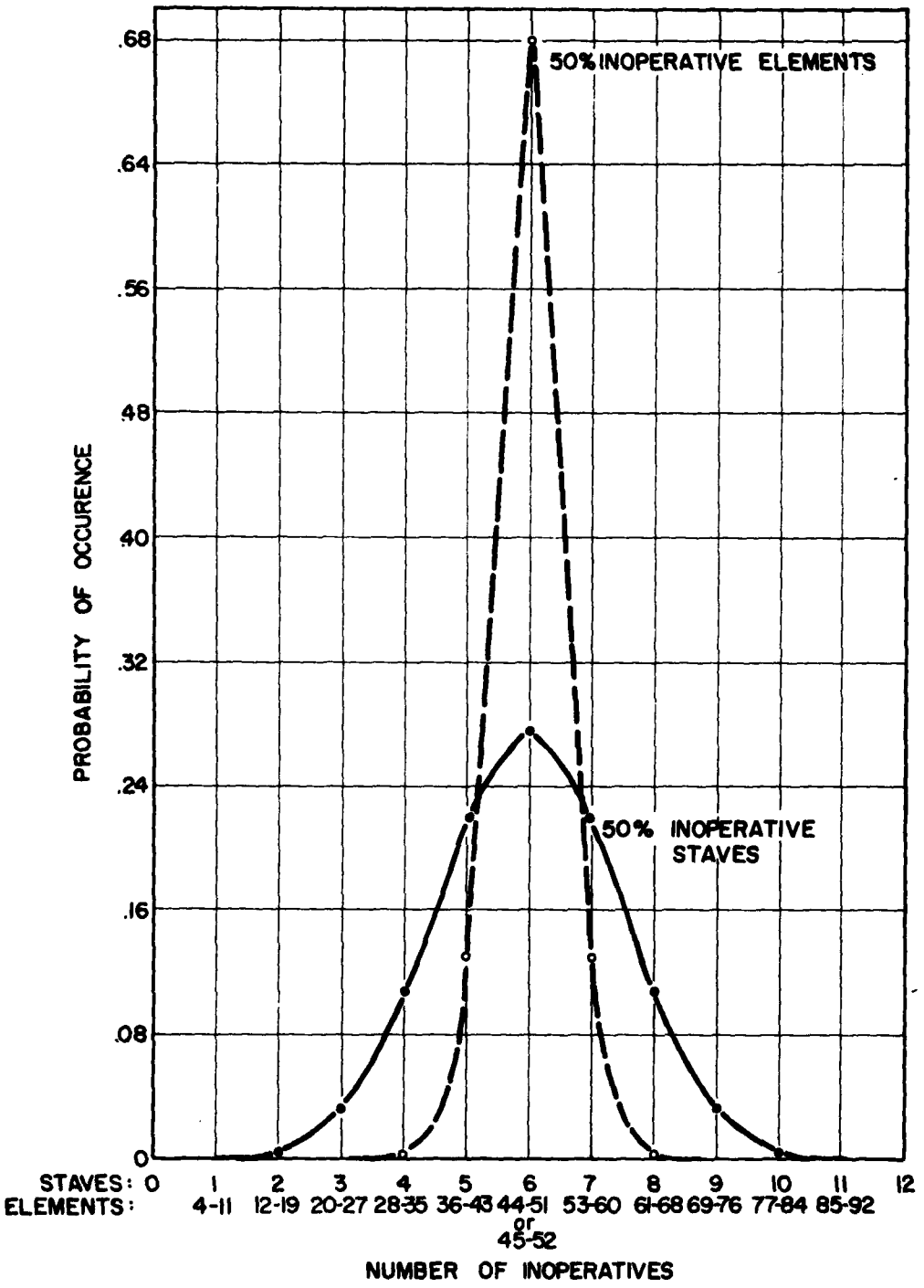

Fig.5 - PROBABILITY DISTRIBUTIONS* OF INOPERATIVE STAVES AND ELEMENTS IN A TWELVE-STAVE ARRAY - ARRAY SELECTED AT RANDOM FROM COMPLETE TRANSDUCERS WITH 50 % OF ELEMENTS OR 50 % OF STAVES INOPERATIVE; PASSIVE RECEPTION

*EQUATION 9 - APPENDIX A

TRACOR, INC DWG A769-35
AUSTIN, TEXAS 11-4-64 BTK-LBH

total number of inoperative staves. This distribution is plotted in Figure 6 for a transducer with 18 (or 50%) inactive staves. From this curve one may conclude that the most likely variation from one array to another is only one stave, but zero, two and three are not unlikely.

The final step in the theoretical development would be to determine the probability that a certain variation in the number of inoperative staves between different 12-stave arrays is the maximum variation present in a transducer. Thus, instead of picking two arrays at random, as for Figure 6, the two extreme arrays in the transducer would be considered to determine the probability of certain maximum variations in the number of inoperative staves in different arrays of the same transducer. One would expect the peak of such a "maximum variation" distribution to be shifted to the right of that in Figure 6. As it turned out, the analytical expression for this "maximum variation" distribution was quite complex and was not readily amenable to numerical computations. Since no simplification was discovered, it was concluded that nonparametric methods offered the best hope for immediate solution of the problem.

The approach taken here was to consider sets of 100 hypothetical transducers (with a specified number of defectives) for each case under analysis. The assumed position of inoperative staves was determined using a random number table and the number of inactive staves or elements in each potential array of each transducer were counted. From these data, the maximum variation in the number of inactives between the two most extreme arrays in each transducer was determined. The results were put into bar graph form and are displayed in Figures 7-10. Figure 7 is for the passive mode with 50% of the staves assumed inoperative, Figure 8 is for the passive mode with 30.6% of the staves inoperative, Figure 9 is for B-scan with 50% of the staves inoperative and Figure 10 is for the passive mode with 29.9% of the <u>elements</u> assumed inoperative.

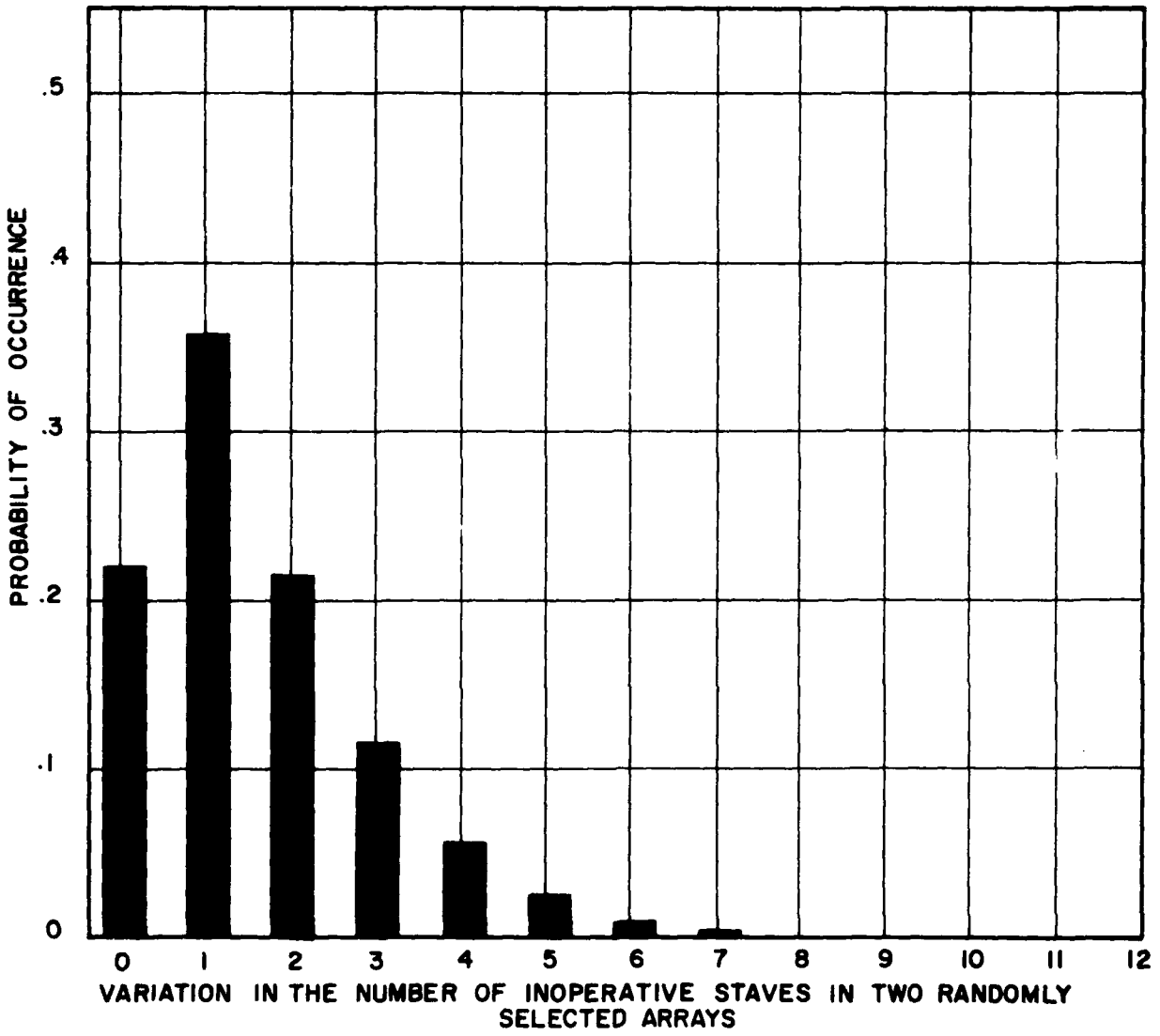

Fig. 6 - THEORETICAL PROBABILITY DISTRIBUTION OF THE VARIATION IN THE NUMBER OF INOPERATIVE STAVES BETWEEN TWO RANDOMLY SELECTED TWELVE-STAVE ARRAYS IN A 50% (18/36) INOPERATIVE STAVE TRANSDUCER IN PASSIVE RECEPTION

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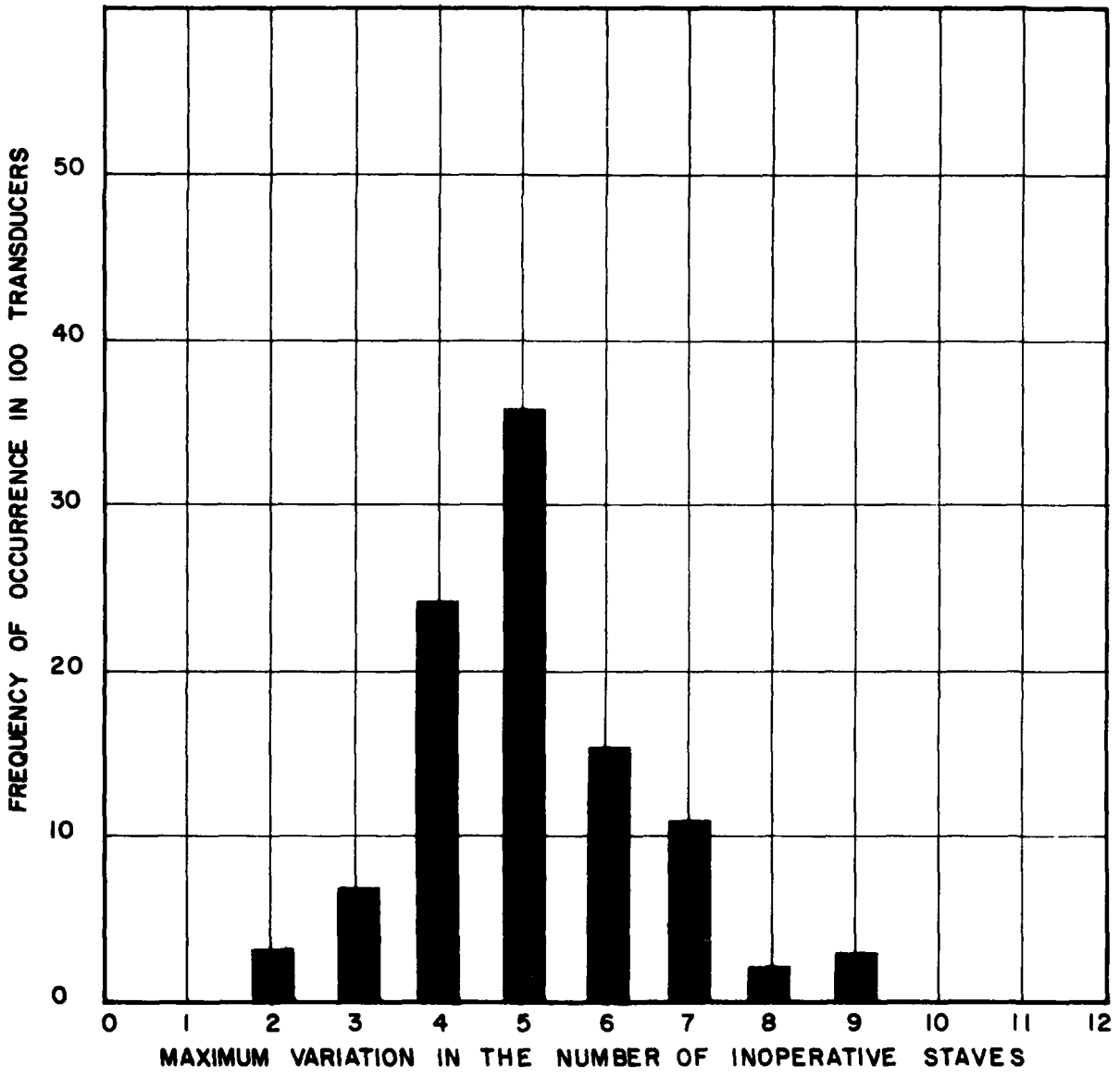

Fig. 7 - VARIATION BETWEEN THE TWO EXTREME TWELVE-STAVE ARRAYS IN 100 HYPOTHETICAL TRANSDUCERS WITH 50% (18/36) RANDOM INOPERATIVE STAVES; PASSIVE RECEPTION

TRACOR, INC. DWGA769-22
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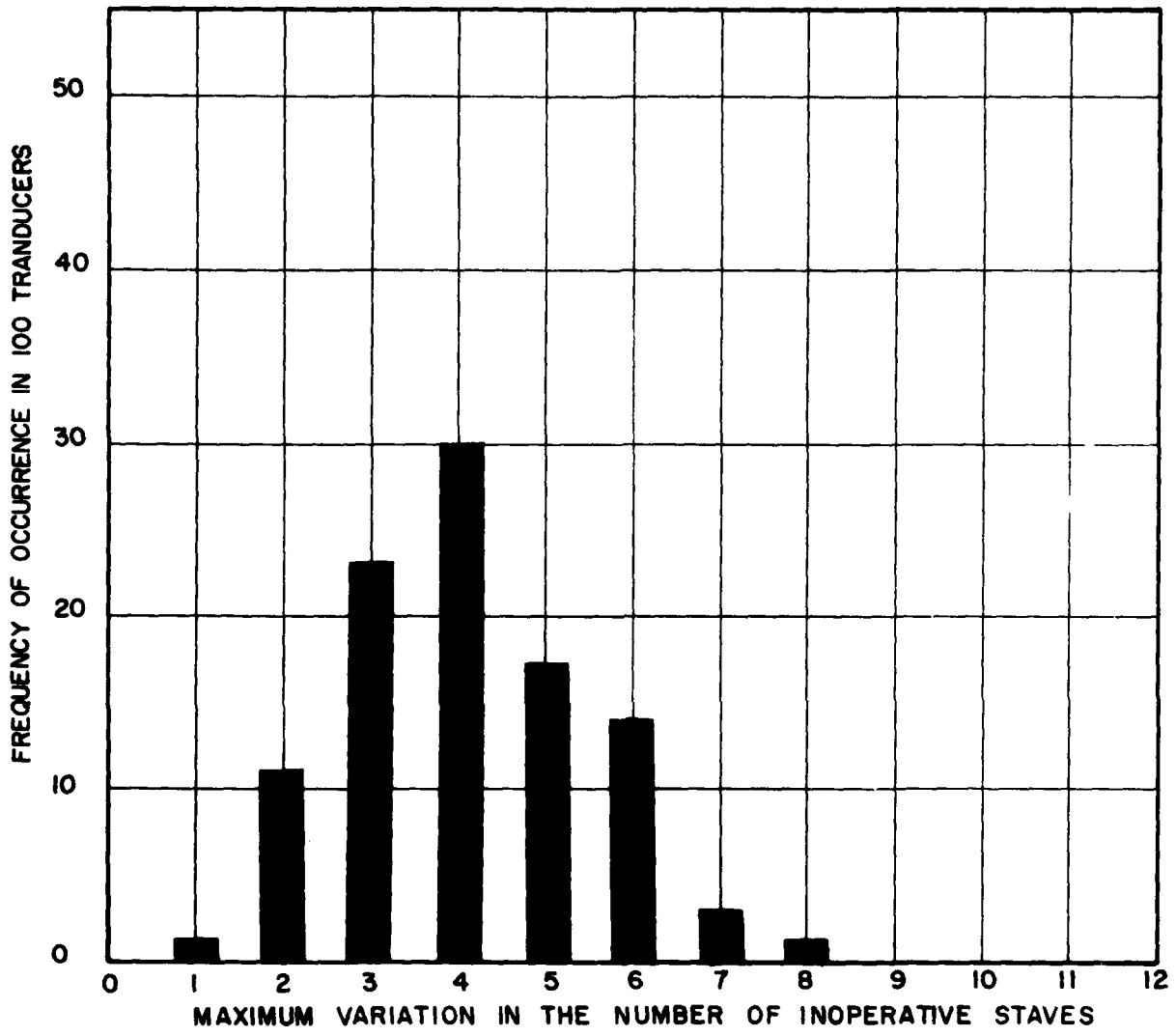

Fig. 8- VARIATION BETWEEN THE TWO EXTREME TWELVE-STAVE ARRAYS IN 100 HYPOTHETICAL TRANDUCERS WITH 30.6% (11/36) RANDOM INOPERATIVE STAVES; PASSIVE RECEPTION

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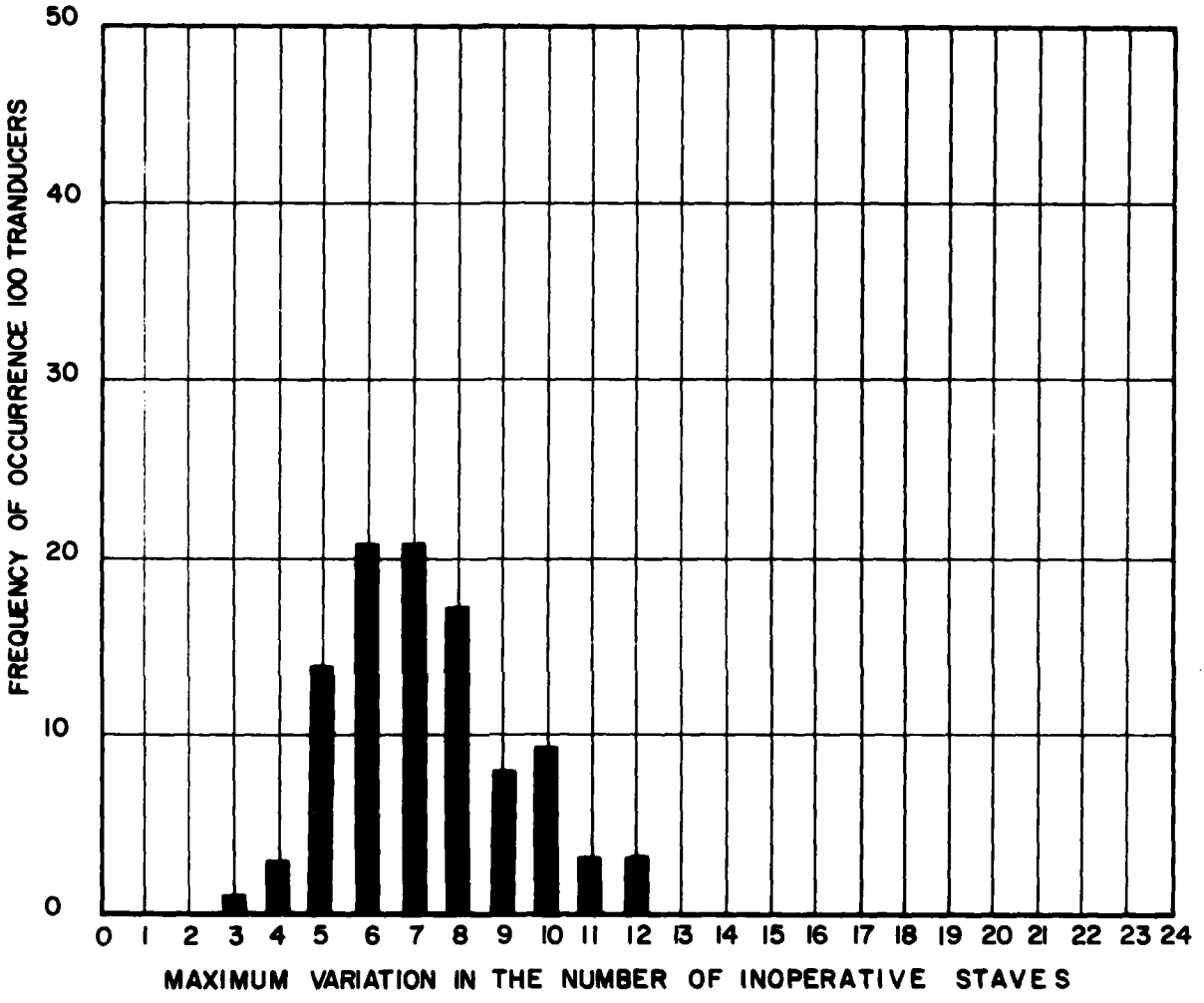

Fig. 9 - VARIATION BETWEEN THE TWO EXTREME TWENTY-FOUR STAVE ARRAYS IN 100 HYPOTHETICAL TRANSDUCERS WITH 50% (36/72) RANDOM INOPERATIVE STAVES; B-SCAN

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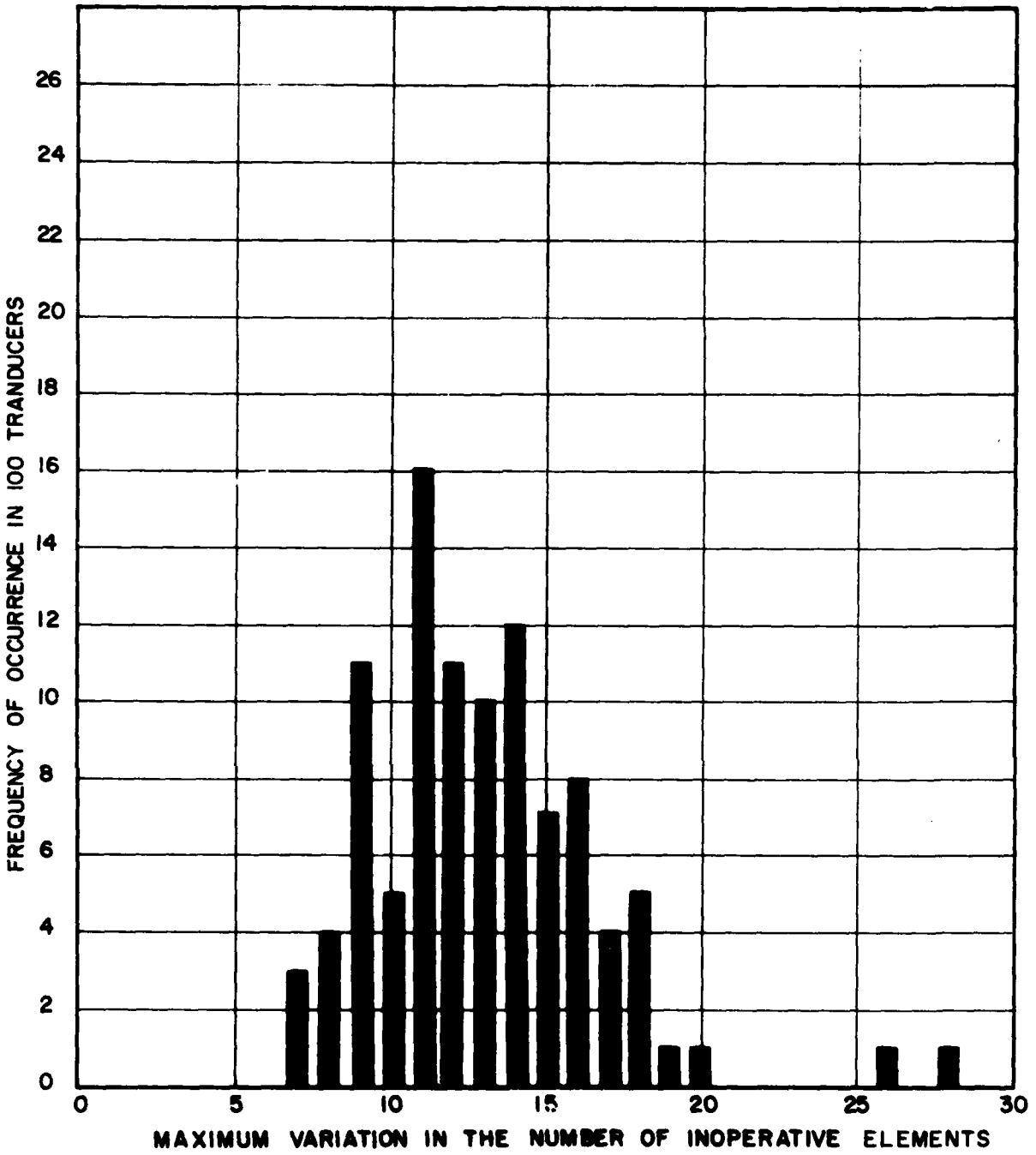

Fig. 10 -VARIATION BETWEEN THE TWO EXTREME TWELVE-STAVE ARRAYS IN 100 HYPOTHETICAL TRANDUCERS WITH 29.9% (86/288) INOPERATIVE ELEMENTS; PASSIVE RECEPTION

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These results were ordered and through the theory of order statistics, confidence intervals were placed on a point which 90% of the maximum variations do not exceed. The median point estimate of the maximum variation of each distribution shown in Figures 7 through 10 was determined and is shown in the first column of Table I. The variations in numbers of staves or elements were translated into approximate decibel equivalents by reference to the appropriate degradation curves as a function of the percentage of inoperatives, (e.g., see the 0° curve for 2.5 kc of Figure 1 in the Passive cases). The median of the distribution is simply the value K of the maximum variation such that 50% of the total population of maximum variations are $\leq K$ and 50% are $\geq K$. Since a transducer will seldom actually have the median variation, it is of interest to determine a variation for which 90% of all maximum variations are equal or less. These values and their decibel equivalents are given with at least 98% confidence in the last two columns of Table I for the four cases considered. For example, in the last case in Table I, the data indicates that in 90% of all transducers with 29.9% of the elements inoperative, the maximum variation in sensitivity between any two beams in the passive mode would be less than or equal to 2.2 dB.

The variation problem discussion has been made somewhat more lengthy than would normally be required since it appears that this is the first time that this aspect of transducer response has been analyzed. It must be re-emphasized that the case of inoperative staves (defined in the INTRODUCTION) alone does not correspond to practical reality, but has been analyzed and discussed here only to illustrate a method of approach and to point up the necessity for highly reliable components in stave signal amplification and handling.

Some conclusions from this portion of the study are that the variation problem is worsened as the percentage of

TABLE I. Statistical Results from a Nonparametric Analysis of Groups of Transducers with an Assumed Percentage of Inactive Staves or Elements.

The variations shown are maximum variations in the number of inoperative 12-stave (or 96 element) arrays in a 36-stave (or 288 element) transducer. The data are based on 100 hypothetical transducers in each category and all data were determined with 98% confidence or greater.

	Median Point Estimate of the Max. Variation		Variations for which 90% of all maximum variations are equal or less with at least 98% confidence.	
	Staves or Elements	Sensitivity	Staves or Elements	Sensitivity
Passive (2.5 kc) 50% Inactive Staves (18 out of 36 total)	5 staves	7 dB	≤ 7 staves	≤10.5 dB
Passive (2.5 kc) 30.6% Inactive Staves (11 out of 36 total)	4 staves	4.5 dB	≤ 6 staves	≤ 6.8 dB
B-scan* (3.5 kc) 50% Inactive Staves (36 out of 72 total)	7 staves	5.5 dB	≤10 staves	≤ 7.8 dB
Passive (2.5 kc) 29.9% Inactive Elements (86 out of 288)	12 elements	1.5 dB	≤18 elements	≤ 2.2 dB

*The maximum variations in the B-scan are between 24-stave arrays in a 72-stave transducer.

inoperatives increases, and as the number of "units" in an array decreases (see Fig. 5). Thus the variation in passive reception is somewhat worse than in B-scan reception, and the variation due to inoperative staves is much more serious than for the same percentage of inoperative elements. However, as previously noted, the degradations in receiving sensitivity can be partially compensated and consequently the increase of side lobe level is the more significant criterion due to possible false bearing indications.

B. Active Modes

1. A-Scan

The A-scan console is the operating center for Bottom Bounce and Convergence Zone modes. It employs twelve receiving beams which are formed simultaneously at any one of the nine possible depression angles. These beams are spaced at 10° intervals in azimuth, and are approximately $8\text{-}1/2^{\circ}$ wide at -6 dB. The signals may be received over three frequency bands, the center one being about 3.5 kc, which was the frequency considered in this part of the study.

There were nine 24-stave arrays (with 8 elements per stave) considered in the Redundancy Report[4], for depression angles of 0° and 30°. These arrays contained various proportions of assumed inoperative elements (or equivalently, inoperative preamplifiers or any combination thereof), ranging in number from 0% to 51-1/2% inoperative. As in the passive case, the primary considerations are the main lobe degradation and the side lobe level. Since the beams are 10° apart, they overlap at approximately $\pm 5^{\circ}$, so that degradations at that angle can be significant.

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[4]See footnote 1.

The computed beam degradation at the pattern peak and at $\pm 5^{o}$ is displayed in Figure 11 for a depression angle of 0° (the 30° depression angle case is very similar). As before, the degradation at the pattern peak (0°) reflects the loss in sensitivity due to the assumed inoperative elements, and may be compensated for, to a certain extent, by gain control adjustment. The extent to which this compensation can be effective is limited by the variation in the number of inoperative elements between arrays from different portions of the transducer. That is, if one A-scan beam is formed from an array with 40% inoperative elements and another of the 12 beams if formed from an array with 45% inoperative elements, then the corresponding variation of about 1 dB in the sensitivity of the beams may not be eliminated by gain control adjustment. Such a variation is not unlikely, even with individual beam gain control adjustments. It may be noticed from Figure 11 that the slope of the degradation curves increases with the percentage of inoperative elements. Thus the variation problem is compounded as the number of inoperatives increases.

Another effect worthy of mention is an apparent sharpening, or narrowing, of the main lobe as the percentage of inoperative elements increases. This results in a lower level crossover point between the beams and thus a slight additional decrease in horizontal coverage. The magnitude of the computed degradation of the crossover point with respect to the major lobe peak (neglecting the basic change in sensitivity) for the worst case considered (51.5% inoperative elements) is about 2.4 dB. Although this is a significant change in level, the angular spread of the degradation is so small that the effect on horizontal coverage is very slight.

In Figure 12, the level of the highest sidelobe with respect to the main lobe peak is plotted as a function of the percent inoperatives for 0° and 30° tilt angles. The highest sidelobes generally occurred around $\pm 9^{o}$. Although they

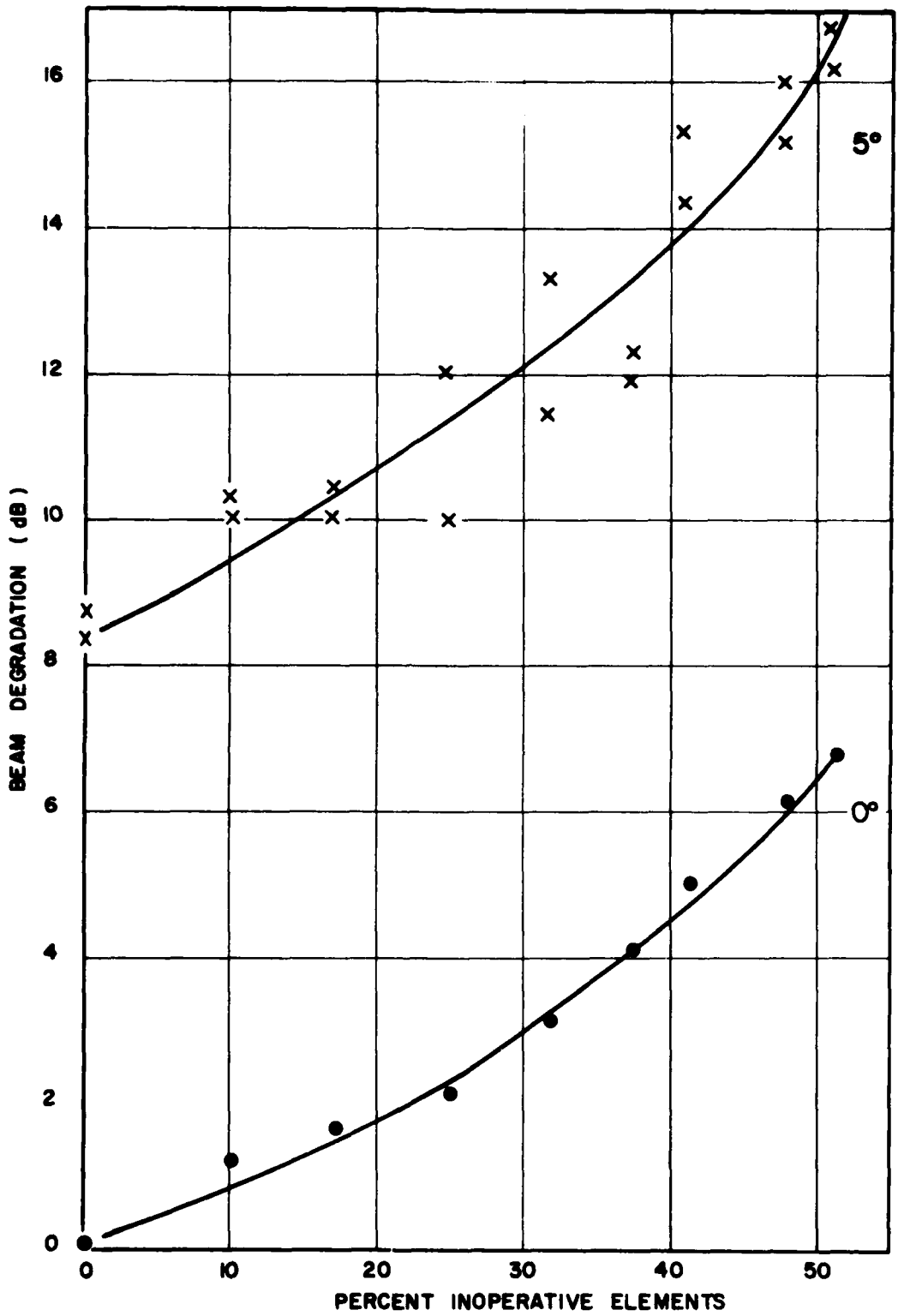

Fig. 11 - BEAM DEGRADATION DUE TO RANDOM INOPERATIVE ELEMENTS; A-SCAN PRESENTATION; 0° TILT ANGLE; 3.5 KC

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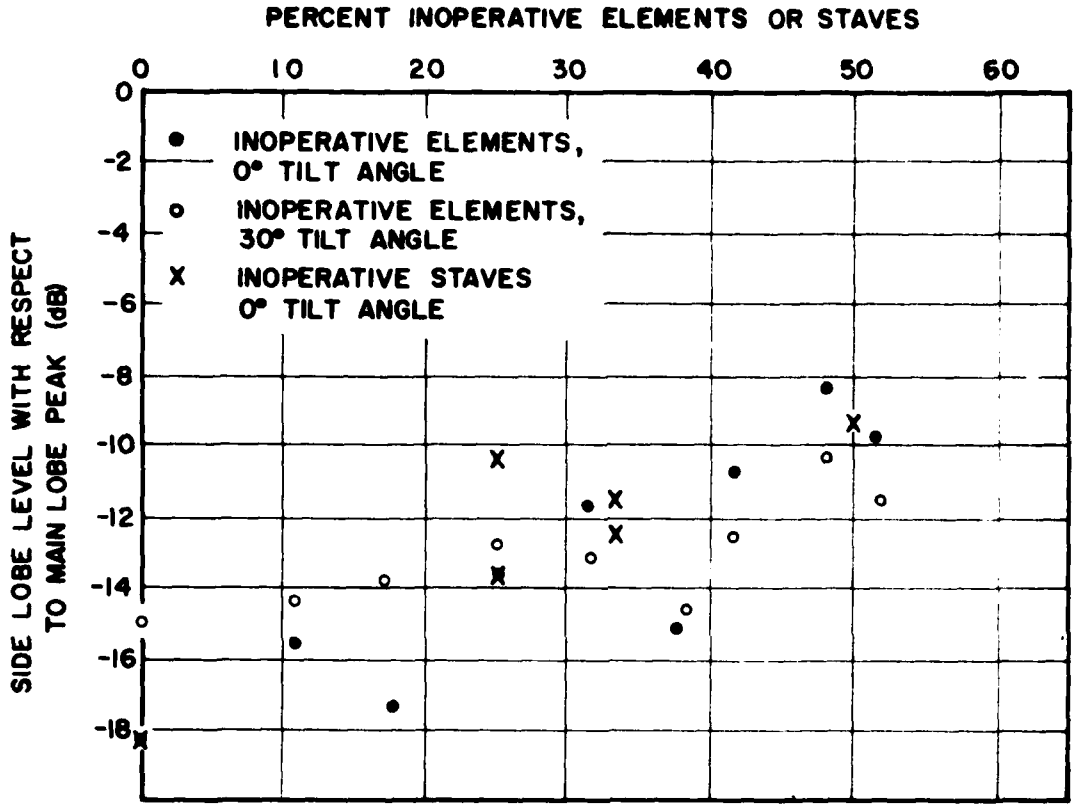

Fig.12 - SIDE LOBE LEVEL FOR TRANSDUCERS WITH RANDOM INOPERATIVE ELEMENTS OR STAVES; HORIZONTAL RECEIVE ; 3.5

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are not nearly so high (due to amplitude shading), as the sidelobes for the passive mode, it is still possible that a signal could be detected on them and cause an erroneous target bearing indication.

There were six 24-stave arrays with randomly located inoperative staves, and five arrays with inoperative staves at specified locations which were considered in the Inoperative Stave Report[5]. A depression angle of 0° was assumed. The ordered arrays had 6 (25%) inoperative staves, while the random arrays were split into three groups of two arrays each: one group with 6 (25%), one with 8 (33-1/2%), and one with 12 (50%) inoperative staves.

The computed main lobe degradation has been plotted in Figure 13. The statements and conclusions regarding the arrays from the Redundancy Report (inoperative elements) also apply here, with the following differences:

(a) Contrary to the inoperative element cases, there is a sizeable variation in the degradation at 5° off the main lobe peak, between arrays with the same number of inoperative staves. Whereas the inoperative element main lobes were fairly symmetrical, with the $+5^{o}$ and -5° degradations differing by less than 2 dB, the inoperative stave patterns displayed differences up to 8.7 dB in the random arrays and 13.6 dB in the ordered arrays. This effect is directly related to the variation problem discussed in the analytical section of part II A. (i.e., a localized variation in the number of inoperative staves is more likely than a localized variation in the number of inoperative elements - see Figure 5). The magnitude of the

[5] See footnote 2.

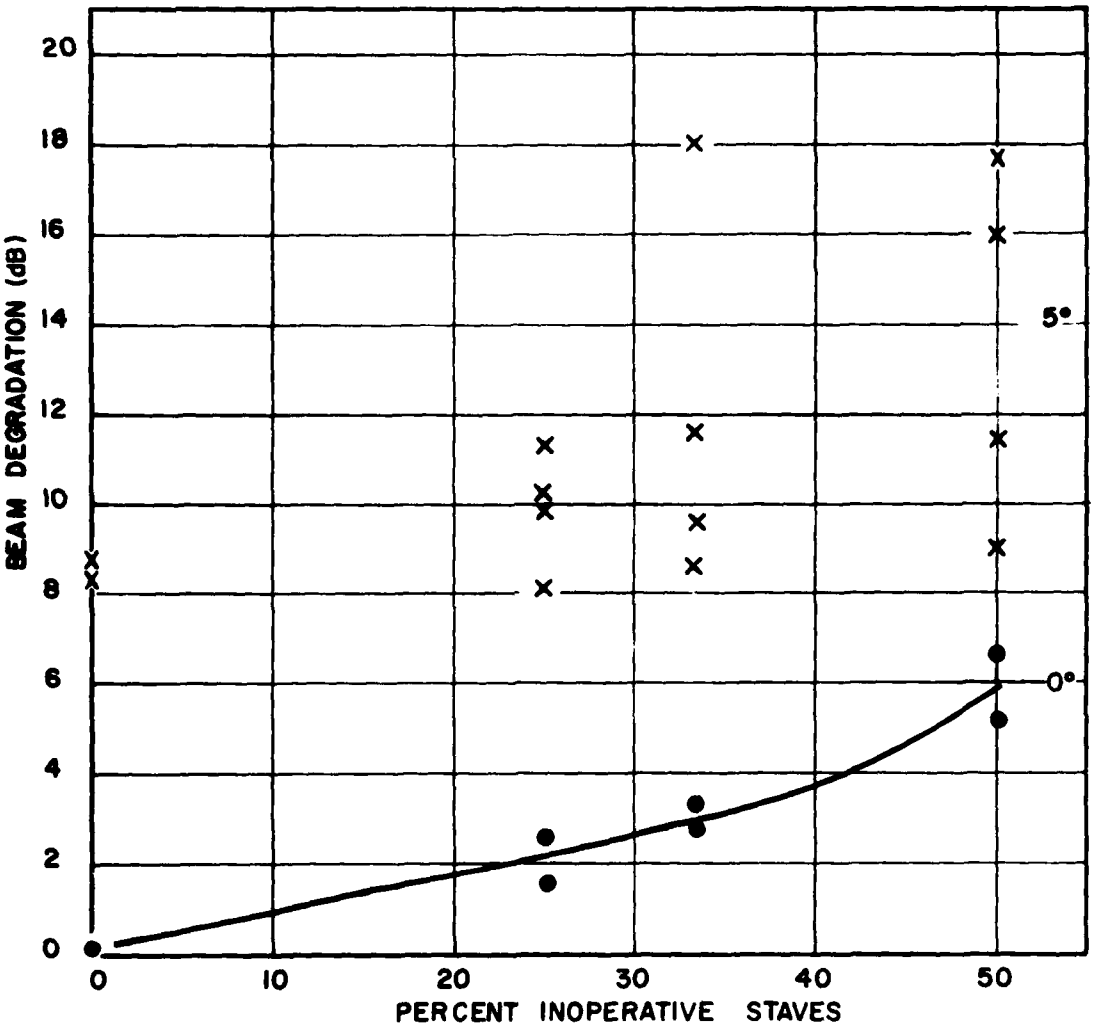

Fig. 13 - BEAM DEGRADATION DUE TO RANDOM INOPERATIVE STAVES; A-SCAN PRESENTATION; 0° TILT ANGLE; 3.5 KC

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variation is large because the sides of the main lobe are rather steep at $\pm 5^{o}$. However, as pointed out above, the inoperative stave cases are extreme cases and are not likely to be encountered in practice to the extent that has been discussed here. At any rate, the narrowness (less than 1°) of the "holes" produced by unsymmetrical major lobes would have little effect on horizontal coverage.

(b) A factor that affects the problem of variation from one array to the next is amplitude shading. With shading, an inoperative stave at the center of an array causes more beam degradation than an inoperative stave at the array edge. This effect is particularly evident in patterns where the arrays had a group of inoperative staves located at the center or edge of the array.

Sidelobe levels for the beams computed in the Inoperative Stave Report are plotted in Figure 12 along with those for the beams computed in the Redundancy Report. It is apparent that the sidelobes are approximately at the same level in both cases if the percentage of inoperative elements is the same as the percentage of inoperative staves. Again there is some possibility that an erroneous target bearing indication could result from signal detection on a sidelobe from an array with a large number of inoperative staves (e.g. of the order of 50% inoperative).

In point of fact, there is a high degree of interrelation between the twelve beams of an A-scan presentation because any two adjacent beams come from arrays with 22 of their 24 staves in common. To gain an appreciation for the variation problem in a "typical" case, twelve interrelated A-scan beam patterns were computed from a 46 stave portion of a transducer with 39.7% randomly located inoperative elements. The major lobes of these patterns are plotted in Figure 14, and the significant degradations are given in Table II. The complete patterns are shown in Appendix C.

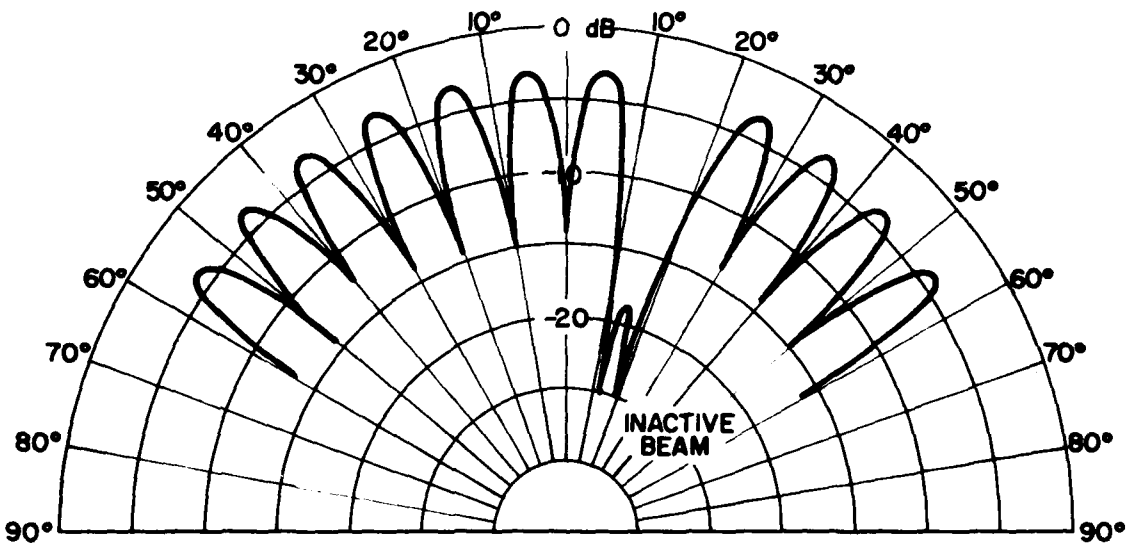

Fig. 14 - A-SCAN PRESENTATION; 40% RANDOM INOPERATIVE ELEMENTS; 0° TILT ANGLE; 3.5 KC

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TABLE II. Degradations Associated with 12 Interrelated A-scan Beams with 40% Randomly Located Inoperative Elements.

	0° Degradation (peak sensitivity)	5° Degradation (Between Beams)	Sidelobe Level (w.r.t. Main Lobe with all-elements-active)	% Inactive Elements in an array
Maximum	-3.8 dB	-15.1 dB	-21.5 dB	41.2
Minimum	-2.8	-13.8	-16.2	34.4
Average	-3.14	-14.3	-18.8	36.9
Standard Deviation	0.33	0.41	1.46	2.04

It has been assumed that the 2.8 dB degradation in sensitivity can be corrected by overall gain control adjustment. However, the 1.0 dB variation in sensitivity (3.8 - 2.8), though theoretically correctable with individual beam gain controls, may be best ignored as operationally insignificant. The maximum (corrected) degradation at the crossover points was 12.3 dB (15.1 - 2.8), and the highest sidelobe level was 13.4 dB (-16.2 + 2.8), for this 36.9% inoperative elements case - as compared to 8.6 dB degradation between beams and a sidelobe level of -18.3 dB for the all-elements-active case.

Thus we see that in this "typical" case of about 40% inoperative elements with a 0° tilt angle, there is, (a) 1.0 dB variation in sensitivity, (b) 3.7 dB (12.3 - 8.6) increased degradation between beams (which is due to 1.0 dB variation and 2.7 dB sharpening of the beam), and (c) 4.9 dB (18.3 - 13.4) increase in the sidelobe level. (Notice that the above figures relate the worst cases of the 12 A-scan beams from a 40% inoperative section of a transducer to the 12 uniform A-scan beams that represent a transducer section with all-elements-active.) The

situation described above seems tolerable, though the sidelobe degradation may be excessive.

To summarize the conclusions regarding the effect of redundant failures on the horizontal coverage for the A-scan presentation, it should be emphasized that:

(a) Roughly speaking, the 12 beams of the A-scan will be uniformly degraded as more and more elements become inoperative (see Figure 14). To the extent to which this is true, compensation for the beam degradation is feasible via gain control adjustment.

(b) However, a closer look at the 12 beams indicates that there is a certain amount of variation in sensitivity from one beam to another. This variation increases as the number of inoperative elements increases, and is considerably worse in the case of inoperative staves than in the case of inoperative elements.

(c) The computed major lobe becomes somewhat narrower as the number of assumed inoperative elements increases, and this increases the degradation of the crossover point between beams. However, this degradation has little effect on horizontal coverage.

(d) The sidelobe level is observed to increase as the number of assumed inoperative elements or staves increases, to the extent that with 50% inactive elements the sidelobe level may be -8.5 dB and signal detection on a sidelobe becomes a practical possibility. This could yield erroneous target bearing indications.

(e) Also, it should be noted that contrary to the situation for passive reception, the loss of an entire beam on the A-scan presentation would produce a significant "hole" in the horizontal coverage. (See Figure 14.) This would result in almost a 10% decrease in the horizontal coverage, which is highly undesirable operationally.

2. B-Scan

The B-scan console is the operating center for surface duct (Omnidirectional Transmission and Rotational Directional Transmission) modes. It utilizes 72 identical video fixed beams spaced at 5° intervals in azimuth at 0° depression angle. The main lobe width of each beam is about $8\text{-}1/2^{o}$ at the -6 dB points. As in the A-scan cases, a frequency of 3.5 kc has been used in this part of the study.

Thus the specification for the B-scan receiving beam patterns differs from the A-scan specifications only in the number and spacing of beams, and not in the nature of the individual beams. Accordingly it is possible to utilize the same beam patterns which were analyzed in the A-scan studies, while focusing attention on the central portions of the major lobes. Since the beams are spaced at 5° intervals, the degradations between $+2.5^{o}$ and -2.5^{o} are of significance.

Since the B-scan receiving beams are spaced twice as close to one another as are the A-scan beams, the degradation between beams is much less in the B-scan. In fact, it may be possible to operate efficiently in these modes even though an entire beam has been lost (as in the case of passive reception, and contrary to the case of A-scan reception). Thus the degradation of the beam patterns at $\pm 5^{o}$ is repeated from the A-scan studies for comparison with the $\pm 2.5^{o}$ degradations, so that the effect of losing an entire beam may be evaluated for any particular situation.

The computed beam degradation for the inoperative element arrays of the Redundancy Report [6] is presented in Figure 15

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[6] See footnote 1.

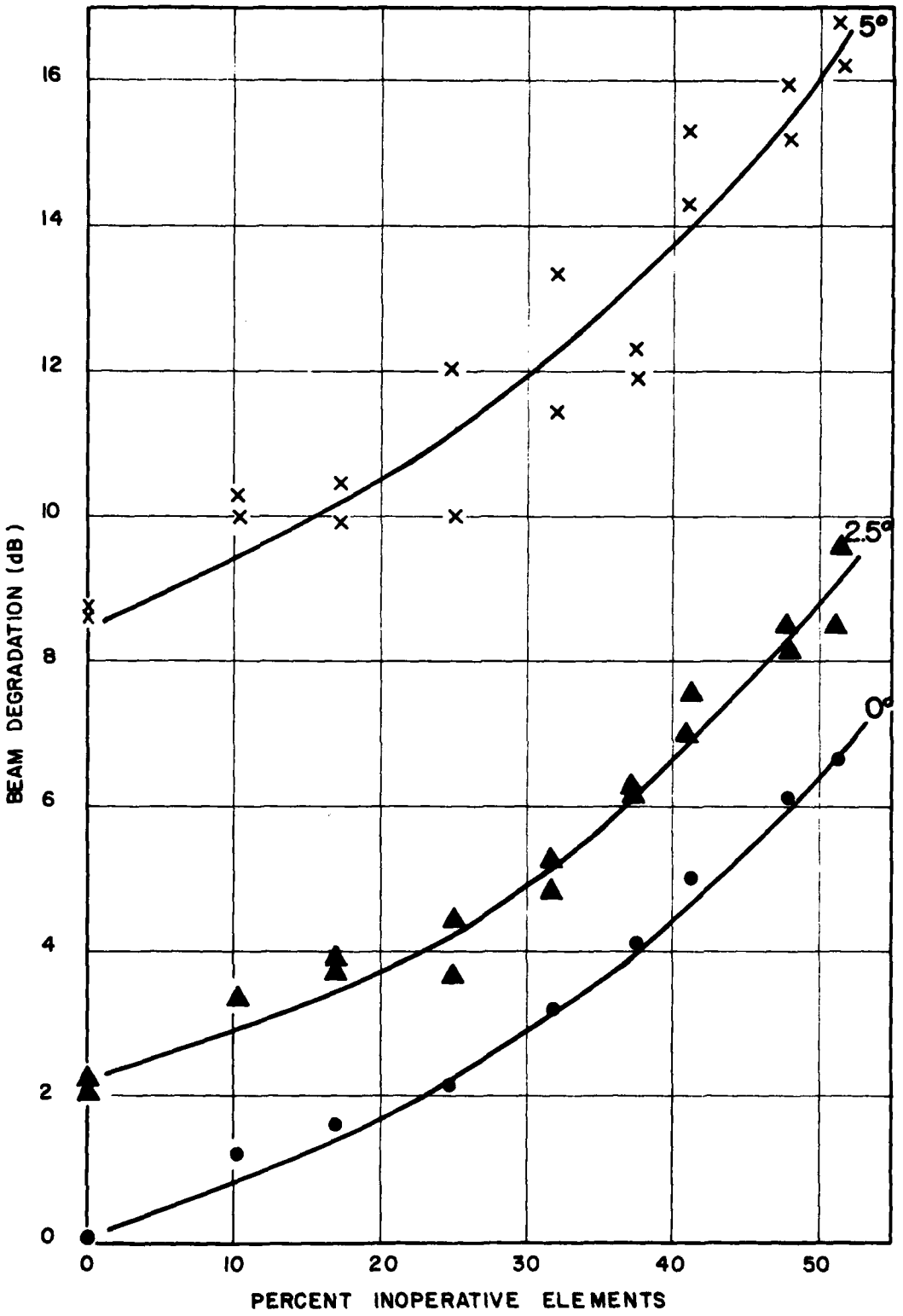

Fig. 15 - BEAM DEGRADATION DUE TO RANDOM INOPERATIVE ELEMENTS; B—SCAN PRESENTATION; 0° TILT ANGLE; 3.5 KC

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for azimuthal angles of 0° (main lobe peak), 2.5^{o}, and 5°. This data is the same sort that was presented regarding the A-scan presentation, and the conclusions to be drawn therefore will differ only in degree from those previously stated. It may be noticed that the loss in beam sensitivity (0° degradation) is the same in A-scan reception as in B-scan reception. However, the B-scan utilizes 72 beams, whereas the A-scan utilizes only 12 beams at a time. Therefore the total variation in sensitivity between the beams from sections of the transducer with the most and least number of inoperative elements will be significantly greater for the B-scan presentation than for the A-scan.

In order to gain an appreciation for the magnitude of this variation, and in order to compare a B-scan pattern with the patterns for passive reception (Figure 3) and A-scan reception (Figure 14), a "typical" transducer was again considered. A complete transducer of 72 staves with eight elements each was analyzed by randomly selecting the position of inoperative elements so that approximately 40% of the total were inoperative. The number of inoperative elements in each of the seventy-two 24-stave arrays was determined by simple counting, and the approximate degradations for each beam were read from the curves of Figure 15. The resulting major lobes have been plotted down to the crossover points in Figure 16. As before, one inoperative beam was assumed simply for demonstration of the effect. The resulting maximum variation in sensitivity (excluding the inoperative beam) is observed to be 2.4 dB in this specific case, as compared with 2.5 dB for a corresponding situation in passive reception, and 1.0 dB for the A-scan reception case. These numbers are for specific "typical" cases, and are presented only to convey general impressions.

The slight sharpening of the major lobes with an increasing number of inoperative elements which was observed for

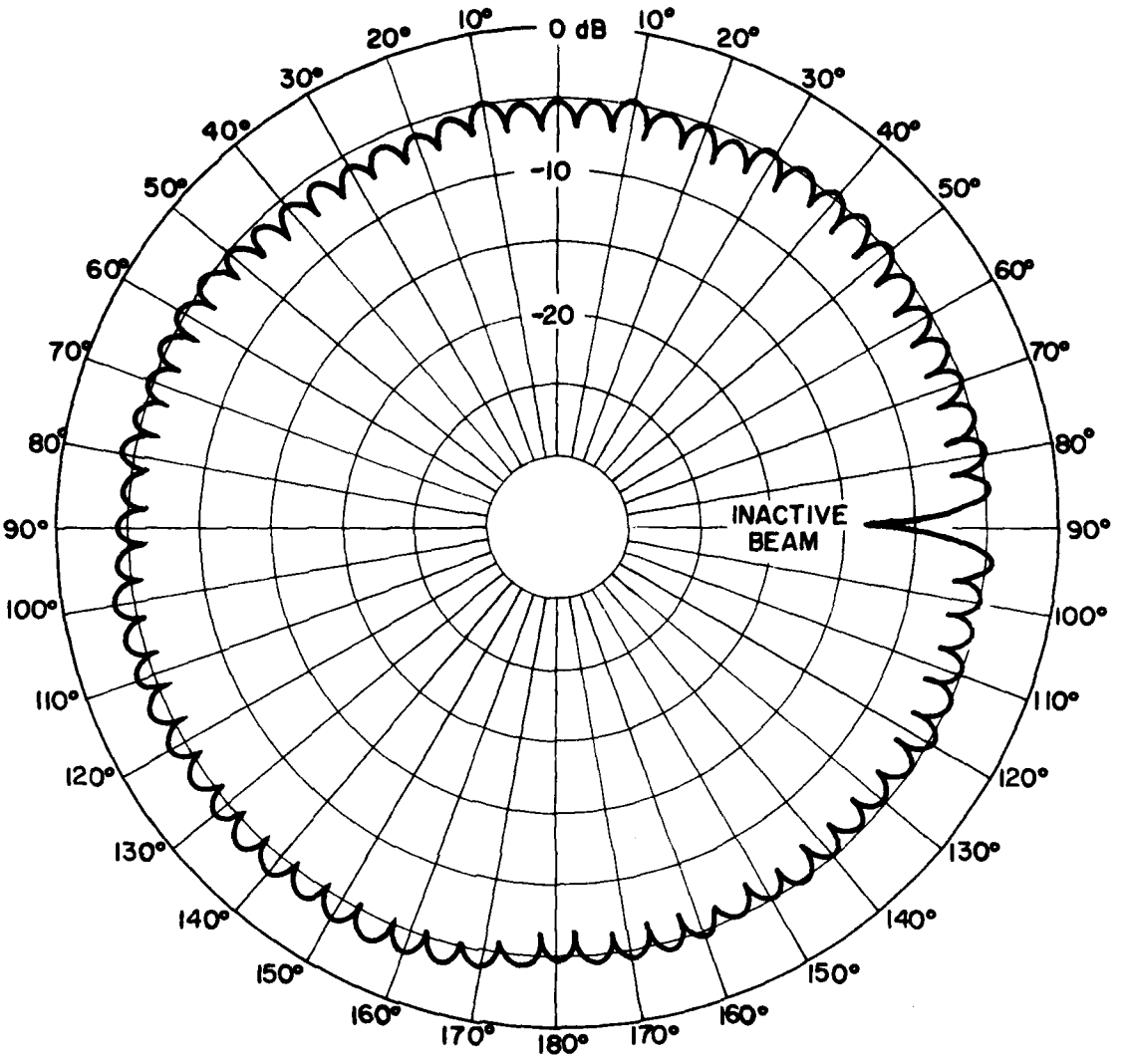

Fig. 16 - B-SCAN RECEPTION 40% RANDOM INOPERATIVE ELEMENTS; 0° TILT ANGLE; 3.5 KC

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A-scan reception is not significant in B-scan reception since only the tips of the major lobes are involved.

The sidelobe level will be no different in B-scan reception than in A-scan reception, and its variation with the percentage of inoperative elements or staves has been illustrated in Figure 12.

The computed beam degradation for the inoperative stave arrays considered in the Inoperative Stave Report[7] is presented in Figure 17 for a 0° tilt angle, and azimuthal angles of 0°, 2.5^{o}, and 5° as before. These data merely confirm previously stated conclusions.

That is, the variation problem is considerably worse for inoperative staves than for inoperative elements (e.g. notice the relative spread of computed points in Figure 15 and 17). This effect dominates the major lobe sharpening effect. Also, the degradation between beams in B-scan is much less serious than in the A-scan presentation (e.g. notice the relative degradation of the 2.5^{o} and the 5° sensitivity).

In summary, the conclusions reached regarding the effect of redundant failures on the horizontal coverage in B-scan presentation are the same as those reached regarding the A-scan presentation, with the following distinctions:

(a) The degradation at the major lobe crossover points is much less serious than in the A-scan presentation since the B-scan beams are twice as close together. Therefore it is possible to operate, at slightly reduced effectiveness, even though an entire beam (but not two adjacent beams) were lost.

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[7]See footnote 2.

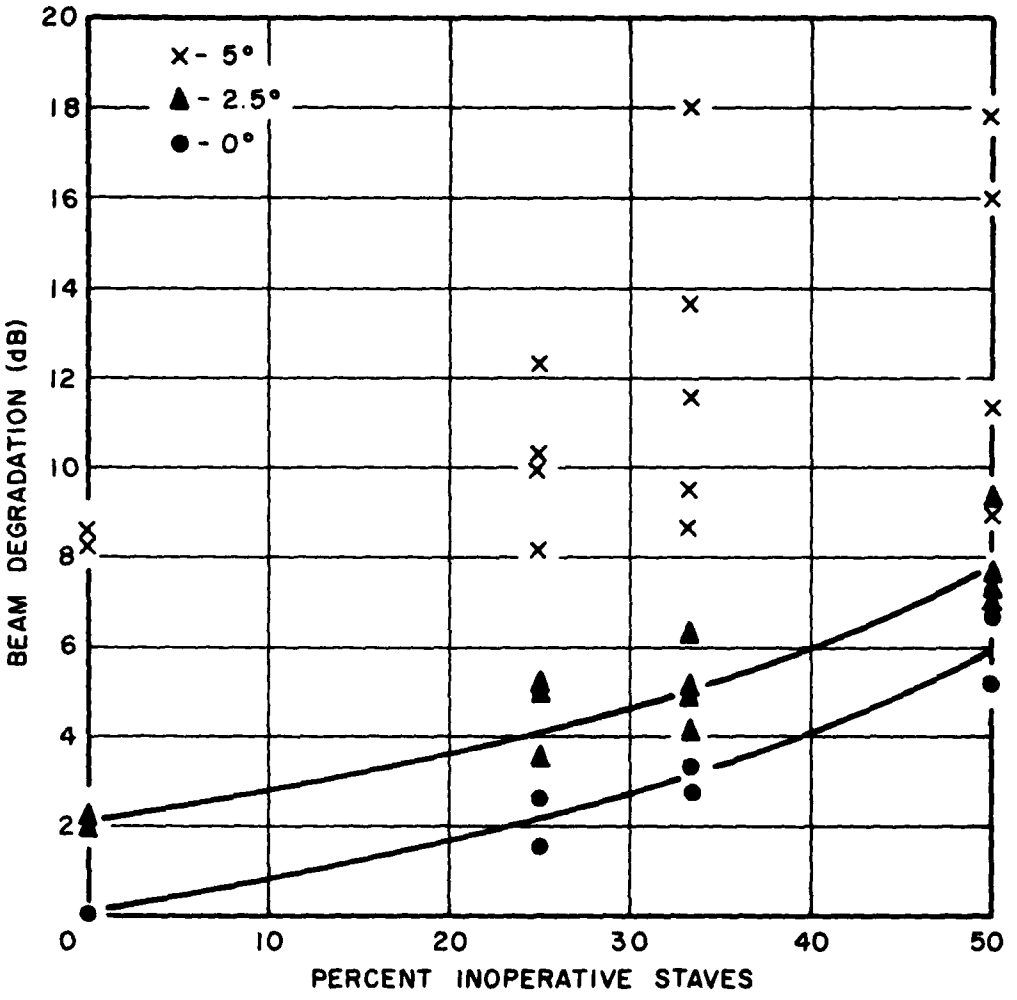

Fig. 17 - BEAM DEGRADATION DUE TO RANDOM INOPERATIVE STAVES

B-SCAN PRESENTATION; 0° TILT ANGLE; 3.5 KC

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(b) The variation in peak sensitivity around the transducer is worse for the B-scan than for the A-scan presentation due to the increased number of beams.

It might also be pointed out that the computed effect of preamplifier or transducer element failures on horizontal coverage in B-scan is very much like that for passive reception. (For example, compare Figures 3 and 16.)

C. Summary of Receive Modes

To conclude this section on the effects of redundant failures on the receive performance of the AN/SQS-26 sonar equipments, the following major points are re-emphasized:

(1) Most of the sensitivity degradation due to random failures of elements or staves can be removed by overall gain adjustment. Only in extremely quiet conditions would amplifier gain limit this adjustment.

(2) There is some statistical variation in sensitivity to be expected around the transducer due to nonuniform distribution of inoperative elements or staves. For up to 50% inoperative elements, this variation is generally less than 2.5 dB, which is within the practical limits of adjustment of the display for optimum detection capability. In the case of up to 50% inoperative staves, the variation might exceed 5 dB and could have a significant effect on horizontal coverage.

(3) Sidelobe level degradation is significant in both inoperative element and inoperative stave cases. Alghough, this effect does not bear directly on horizontal coverage, erroneous target bearing indications are possible.

(4) Inoperative beams can probably be tolerated in the passive and B-scan modes (5° beam spacing) provided two adjacent beams are not inoperative. However a beam loss in A-scan (10° beam spacing) produces about a 10% loss in horizontal coverage

and could not normally be tolerated in operation. It should be noted that relatively rapid ship maneuvers, such as patrolling station, could effectively prevent a fixed hole in horizontal coverage due to a lost fixed beam.

III. TRANSMIT

Consideration of fixed beam horizontal coverage would not be complete without taking account of the transmitted signal. Therefore, power amplifier and transducer element failures will be assessed in terms of their effect on the transmitted beam.

When transducer elements (or equivalently, power amplifiers or any combination thereof) fail, there will be a loss in radiated acoustic power, a decrease in the source level, and a resultant reduction in the effective range of the sonar (in the noise limited case). Contrary to the corresponding situation in reception, it is usually not feasible to attempt to compensate for this reduction in source level by a simple gain control adjustment, because the transducer elements are probably on the verge of cavitation during "normal" power output. Therefore the source level is of major importance in evaluating the sonar transmission capabilities.

The frequency of 3.5 kc has also been used for this part of the study, and the various modes of transmission will now be separately discussed.

A. Surface Duct Modes[8]

1. Omnidirectional Transmission (ODT)

In the ODT mode, all 576 elements (72 staves of 8 elements each) are driven in phase. With all elements active, the transmission beam pattern will be uniform through 360° of azimuth. The equipment specification states that the pattern should maintain this uniformity in the horizontal plane to within ± 1 dB.

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[8]Signals transmitted in the surface duct modes are presented on the B-scan and PPI display when received.

The ODT source level degradation in dB is essentially a linear function of the percentage of inoperative elements, where the computed degradation for 25% inoperatives is about 3 dB, which represents a 50% reduction in area coverage. This value is based on the assumption of no element interaction and of constant pressure sources but does take into account the change in overall directivity index.

In addition to the general decrease in source level, there will be some variation in the source level in the azimuthal plane due to localized concentration of inoperative elements. That is, even though it is assumed that elements fail in random locations in the transducer, statistically the distribution of inoperatives will not be completely uniform. As discussed above in the passive reception section, the azimuthal variation for 50% inoperative elements can be expected to be 2 or 3 dB. Therefore, it is quite conceivable that the ODT uniformity specification of ± 1 dB would be violated for a relatively large number of inoperatives, depending on the equipment uniformity prior to loss of elements.

2. Rotational Directional Transmission (RDT)

In the RDT mode, the transmit beam is formed from 24 adjacent staves, appropriately phased. In some of the AN/SQS-26 equipments, the beam is continuously rotatable through a sector width adjustable from 10° to 360°. This smooth rotation is accomplished through the "inductive commutator," which effectively couples the appropriate staves to their power amplifiers. In addition, some equipments have stepwise RDT operation[9], so that this type of operation will also be discussed here.

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[9]Private communication with BuShips, Code 1631.

In Figure 18, the source level (0°) degradations and the degradation at $\pm 5^{o}$ in azimuth are plotted from data taken from the Redundancy Report[10]. It may be observed that the RDT source level degradation approximates the degradation in receiving sensitivity for the A-scan or B-scan patterns. As a crude rule of thumb, there is approximately 1 dB degradation in source level per 8% inoperative elements - between 0% and 50% inoperative. The effect of source level degradation on loss of horizontal area coverage is shown in Figure 19. For example, a 3 dB degradation results in a coverage of only 50% of that with no degradation, for noise limited cases. For reverberation limited cases, the loss in horizontal area coverage, due to loss in source level, will not exist unless the source level drops below a value where reverberation limitation ceases.

The variation in source level from one beam position to another within one transducer may be anticipated from the previous statistical analysis of the reception modes. It will be a function of both the percentage of inactive elements and the sector width (related to the number of beam positions in the stepwise case). With 40% inoperative elements and 12 beams, (equivalent to a 120° sector), there should be a maximum variation of about 1 dB; while with 50% inoperative elements and 36 beams (equivalent to a 360° sector), the maximum variation should be about 2-1/2 dB.

In stepwise operation, the degradation between adjacent beam positions is of importance. This degradation is seen from Figure 18 to be about 11 dB for the all-elements-active case and varies little with the percent inoperatives up to 50%. This relatively deep "hole" between the beams results from

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[10]See footnote 1.

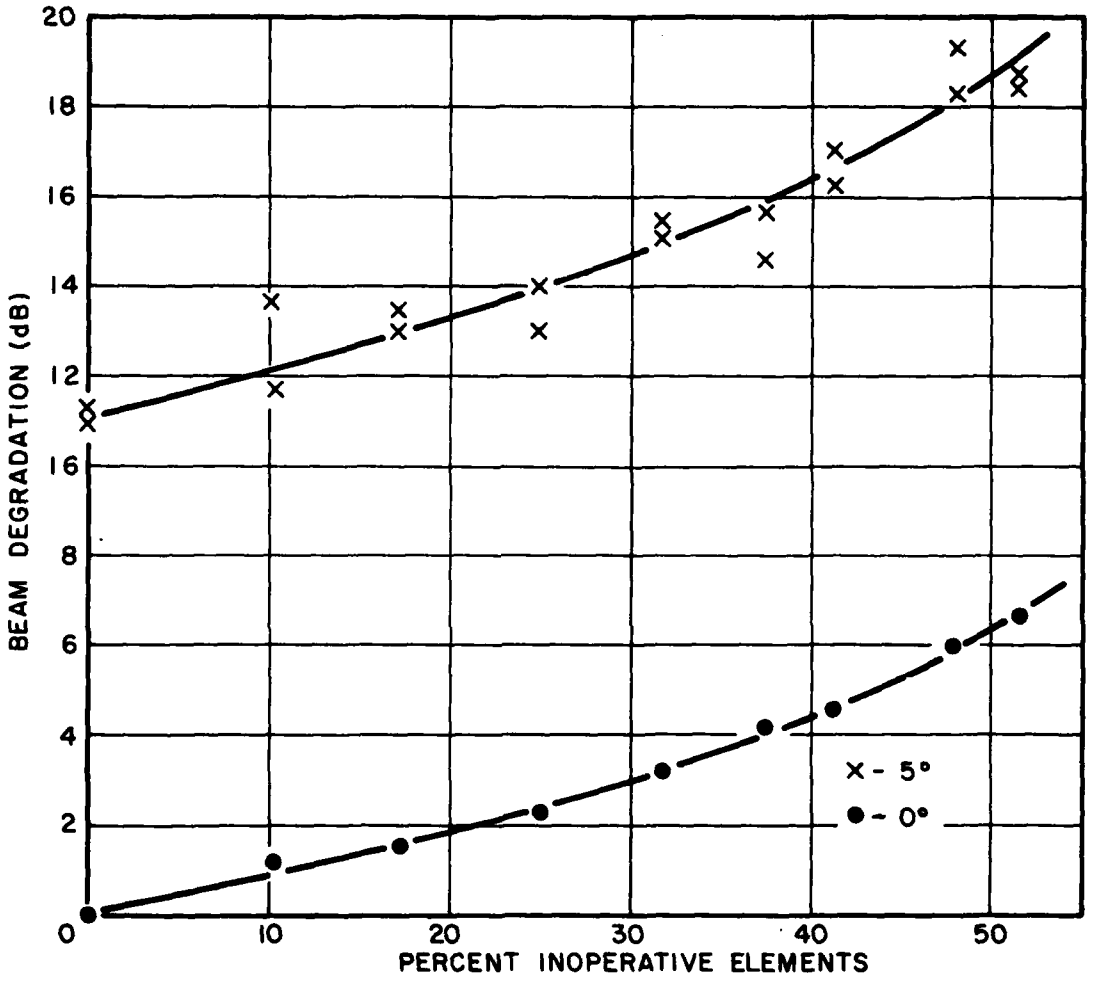

Fig. 18 - SIDE LOBE LEVEL FOR TRANSDUCERS WITH RANDOM INOPERATIVE ELEMENTS; SURFACE DUCT - RDT; 3.5 KC

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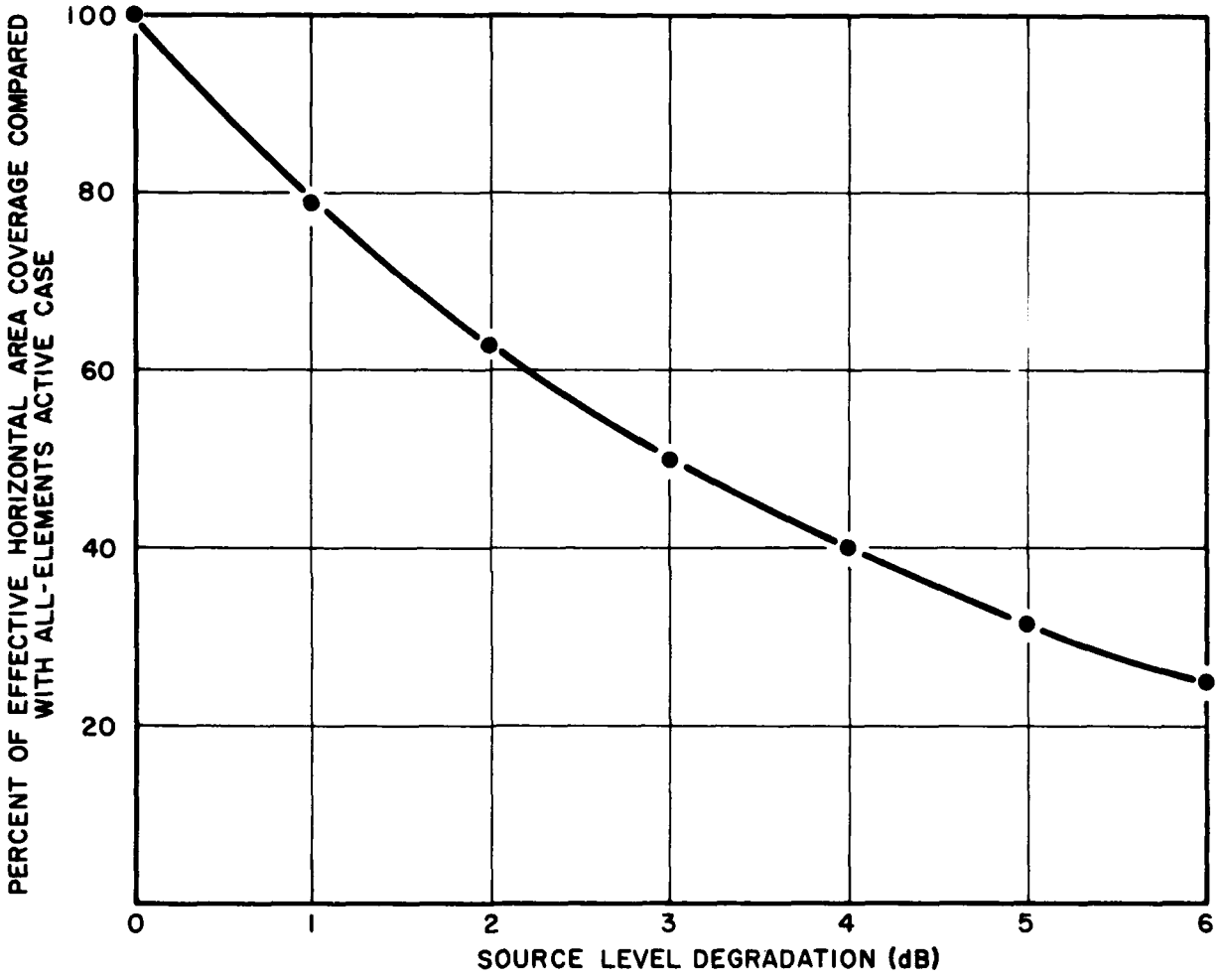

Fig. 19 - EFFECTIVE AREA COVERAGE RESULTING FROM SOURCE LEVEL DEGRADATION - NOISE LIMITED CASE

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the sharpness of the major lobe and the fact that transmission occurs each 10°. The fact that certain sectors of the ocean (between adjacent beam peaks) may receive such a small amount of radiated acoustic power in the RDT mode with stepwise operation is a significant point. One might argue that rapid ship course changes will tend to smear the transmitted beams and ensonify these intrabeam sectors, but there is a good possibility that ship motion could actually widen these sectors in some cases.

The level of the highest sidelobe with respect to the main lobe peak is plotted in Figure 20 as a function of the percent of inoperatives. It may be noticed that the sidelobes for the RDT mode are slightly higher than for the active reception modes, though their significance is much less for noise limited conditions. A high sidelobe on a transmission beam pattern for noise limited conditions is merely an indication that some acoustic power is not being radiated into the intended sector of ocean, and hence it indirectly reflects a source level degradation. However, these high sidelobes can significantly raise the effective reverberation level. A high sidelobe in transmit might also be a significant factor in multiship operations.

In summary, the source level degradation is very much like the degradation of the A-scan or B-scan receiving beams and can be very significant in loss of area coverage in the noise limited case. The total maximum variation in source level between separate beam positions, or between different positions in the transmitting sector, is a function of the selected sector width. For example, with 40% inoperative elements, there would be a maximum variation of about 1 dB in a 120° sector, and about 2 dB in a 360° sector. The sidelobe levels are quite tolerable except in the reverberation limited condition, but a point of concern in stepwise operation is the degradation between beam positions, which reflects the low acoustic power radiated into these sectors of the ocean.

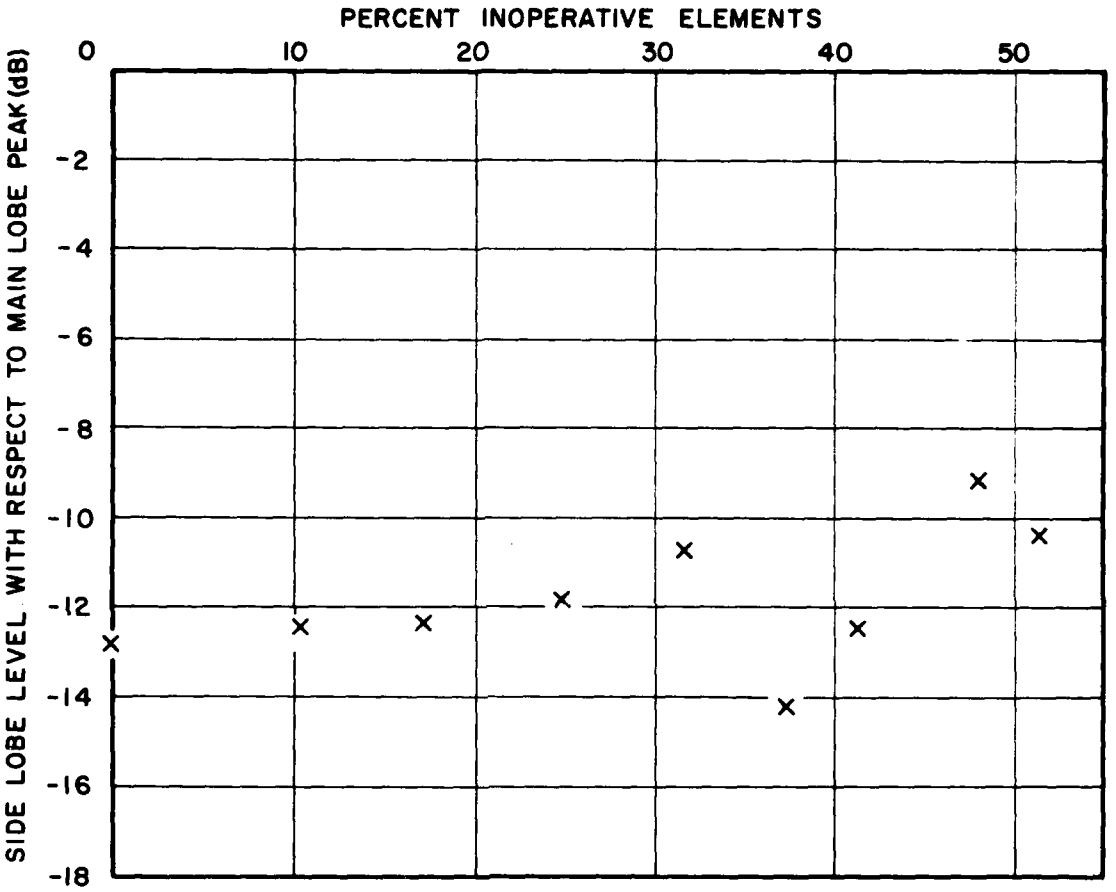

Fig. 20 - SIDE LOBE LEVEL FOR TRANSDUCERS WITH RANDOM INOPERATIVE ELEMENTS; SURFACE DUCT - RDT; 3.5 KC

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B. Bottom Bounce Mode (BB)[11]

In the bottom bounce mode, each transmit beam is formed from a set of 24 adjacent staves appropriately phased. The beams are 45° wide at -6 dB, and any one of the nine tilt angles may be selected. It is possible to use a single 45° beam transmission when tracking, or to have three 45° beam transmissions - followed immediately by an ODT in the horizontal plane (BB-ODT). In this latter case, the BB beam centers are separated by 40° of azimuth.

The following quantities were established as criteria for judging the "quality" of the beam patterns:

(a) The average source level over the beam width.
(b) The degradation at ±20° of azimuth (near the pattern edge) with respect to the all-elements-active pattern peak. Notice that the beams overlap at 20° in the BB-ODT mode.
(c) The degradation of the deepest "valley" of the beam pattern with respect to the all-elements-active pattern peak.
(d) Some indication of the angular width of the "valleys" in the patterns.
(e) The level of the highest sidelobe with respect to the pattern peak.

The first three quantities are plotted in Figure 21 from the arrays in the Redundancy Report[12] at a tilt angle of 30°. The source level is observed to degrade at approximately the same

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[11] Signals transmitted in the bottom bounce mode are presented on the A-scan display when received.

[12] See footnote 1.

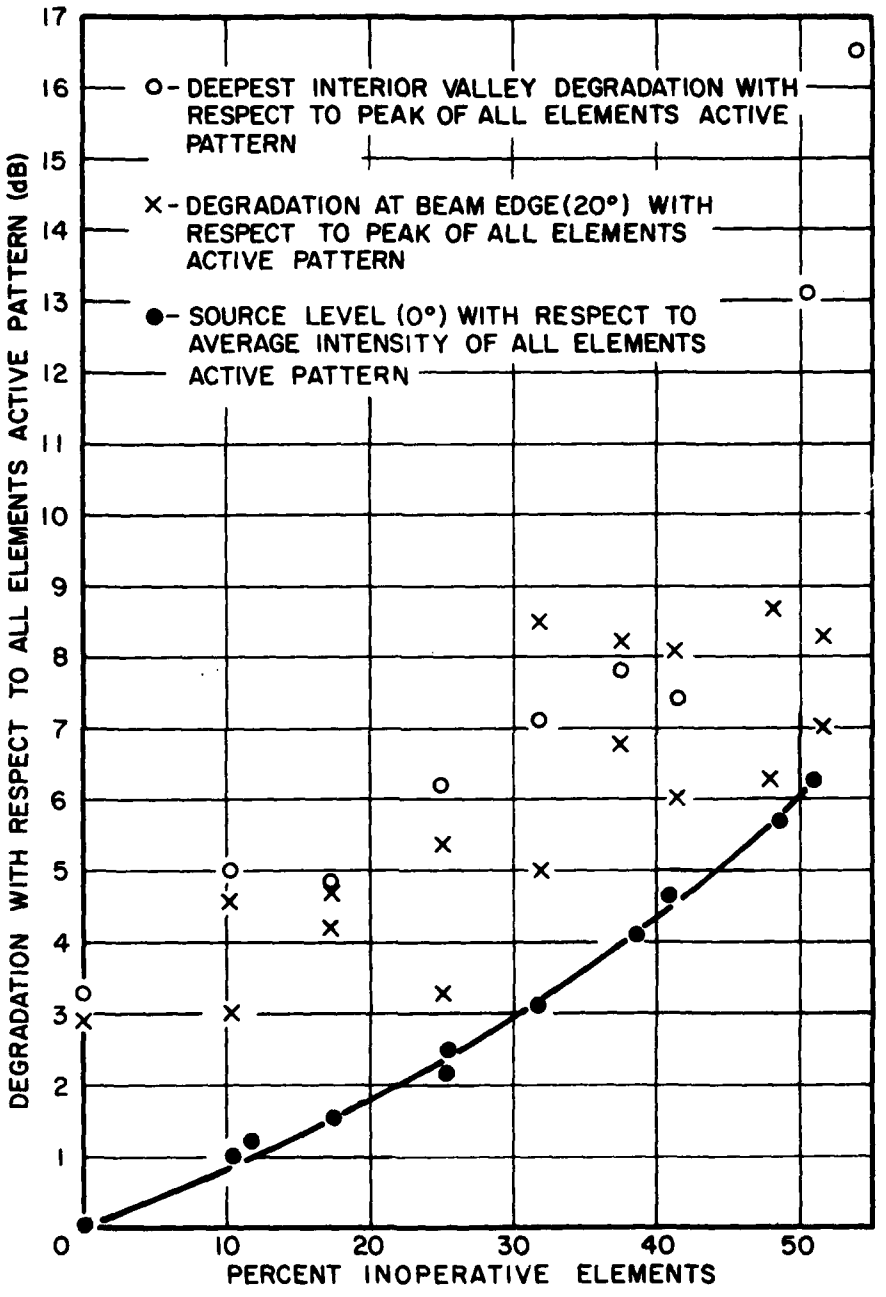

Fig. 21 - DEGRADATION OF 45° BOTTOM BOUNCE TRANSMISSION BEAM PATTERN WITH RANDOM INOPERATIVE ELEMENTS; 30° TILT ANGLE; 3.5 KC

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rate as for the RDT mode. The data on the intensity degradation at the pattern edge (or between patterns for BB-ODT) indicates that the acoustic power radiated at the edges is certainly less than the average source level, but it is not excessively low. If $\pm 22.5^{o}$ rather than $\pm 20^{o}$ is considered the pattern edge, the degradation there will be 1 to 2 dB less than at $\pm 20^{o}$. The data on the interior valley degradation shows that as a rule the intensity in the deepest valley (usually located at $\pm 6^{o}$) is less than at the pattern edge. Furthermore, the valley degradation is seen to increase drastically when more than 40% of the transducer elements are assumed inactive. Thus the transmission pattern for 50% inactive elements has "holes" of the order of 10dB deep.

However, as well as the depth of the "holes," it is necessary to know their angular width to evaluate their effect on horizontal coverage. An attempt to demonstrate the combination of depth and angular width graphically for one case is shown in Figure 22. This is a plot of the total angular extent (θ_T) of those portions of the beam pattern whose intensity reduction exceeds the level δ. The all-elements-active case is shown there in addition to the case for 51.5% assumed inoperative elements. For the latter array, it may be seen that there is a 3.2^{o} sector in each 40° sector of ocean (8% of the total) receiving acoustic power whose intensity is down more than 14 dB from the peak intensity of the all-elements-active pattern. This 8% sector is a significant reduction in coverage; however, this was the worst case computed, and arrays with less than about 40% assumed inactive elements did not exhibit this undesirable characteristic. The reason that the degradation is counted from the all-elements-active peak is that no gain adjustment is allowable, so that the total degradation is the one which counts.

The level of the highest sidelobe with respect to the pattern peak has been plotted in Figure 23 for the 45° beam cases. The sidelobe levels appear to be excessive, but part of the problem

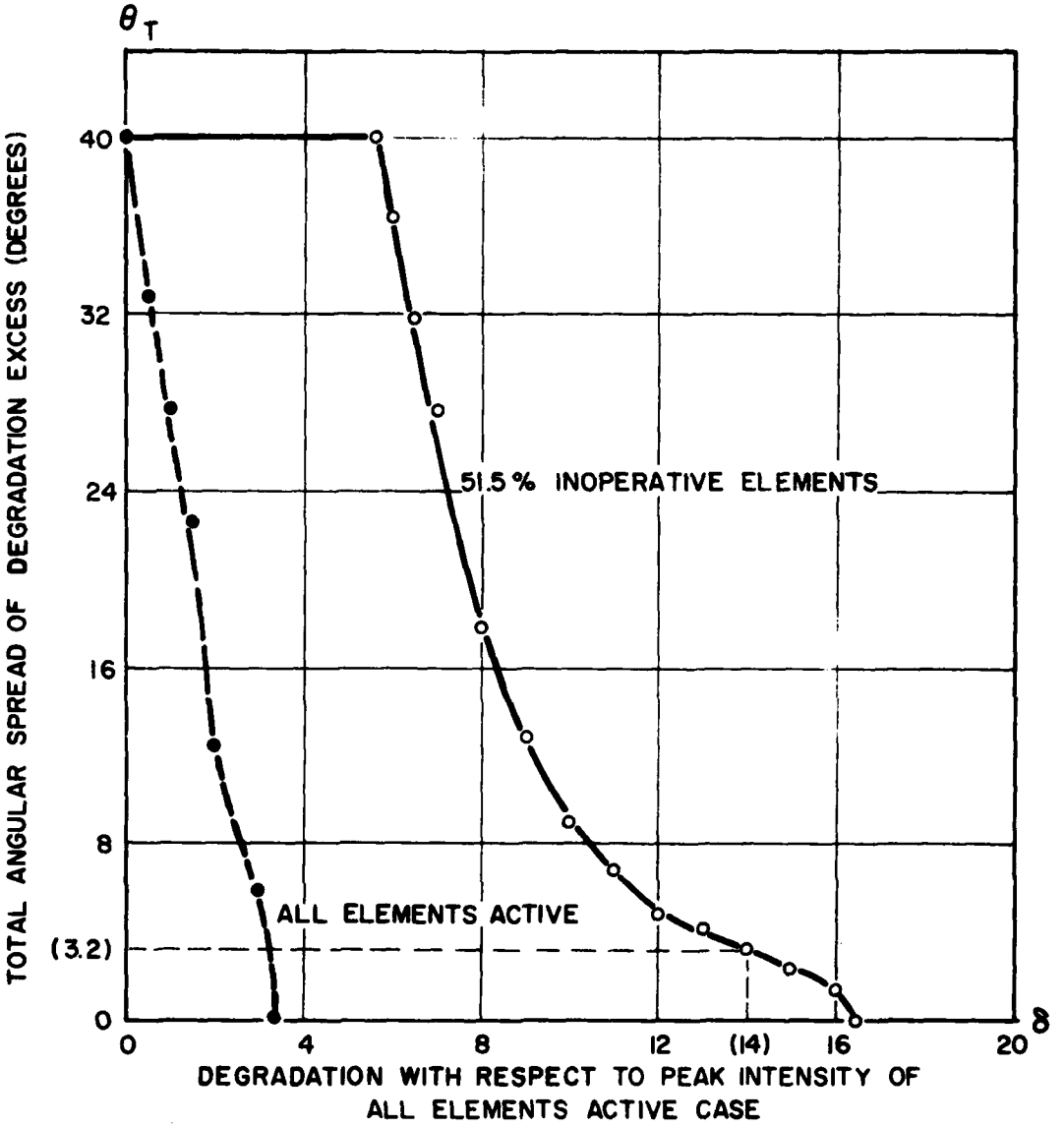

Fig.22-PROFILE OF TOTAL BEAM PATTERN VALLEY WIDTH FOR DIFFERENT LEVELS OF DEGRADATION; BOTTOM BOUNCE TRANSMISSION; 45° BEAM WIDTH; 30° TILT ANGLE ;3.5 KC

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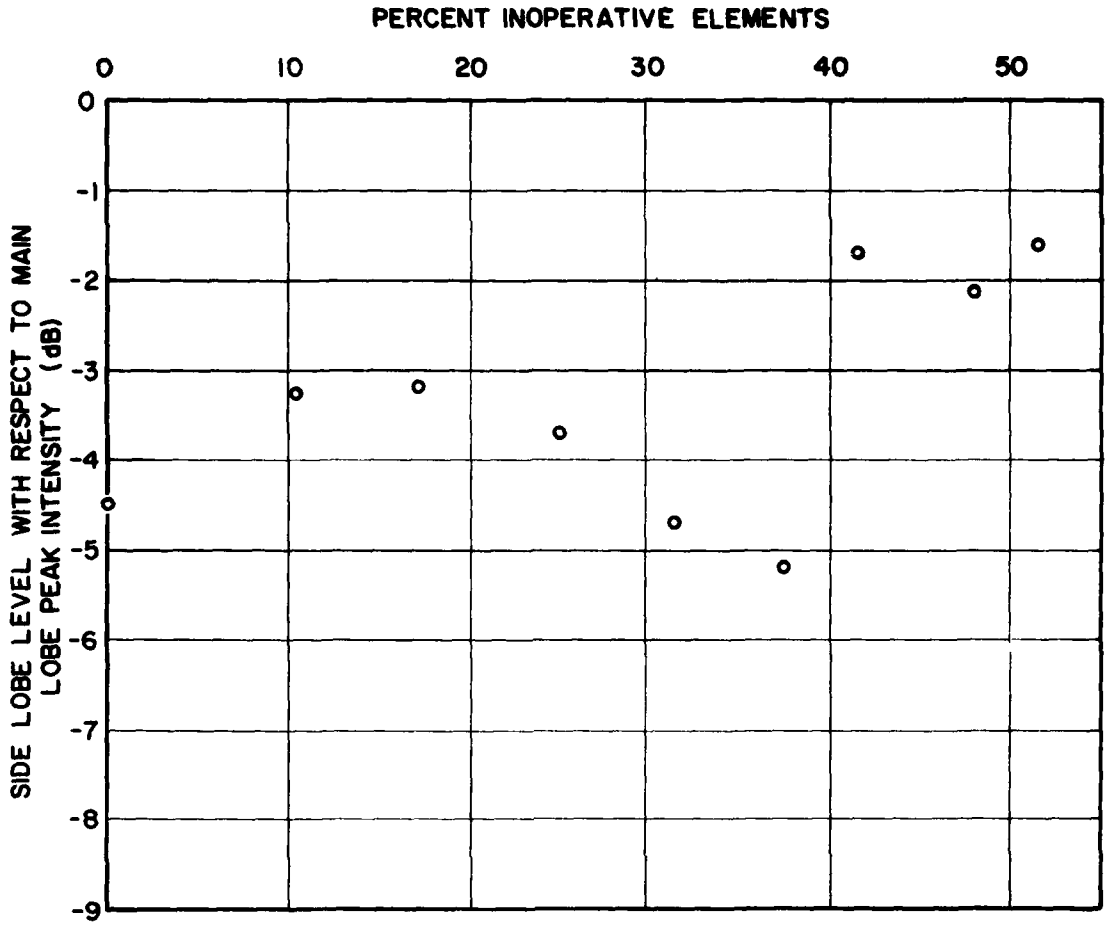

Fig.23- SIDE LOBE LEVEL FOR TRANSDUCERS WITH RANDOM INOPERATIVE ELEMENTS; BOTTOM BOUNCE TRANSMISSION; 45° BEAM; 30° TILT ANGLE ; 3.5 KC

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is in deciding what part of the pattern constitutes the sidelobes. It could be interpreted that the highest portion of the pattern outside the specified major lobe is effectively the highest sidelobe. This interpretation was used here, but several other approaches could be taken. Clearly, a more detailed study of the overall sidelobe problem is needed to clarify this and other questions relating to sidelobes and their effect on system performance.

In summary, the source level degradation followed the same general pattern as previously; namely about 1 dB for each 8% inoperative elements. This can represent a significant reduction in horizontal area coverage in noise limited cases. There were few computed pattern effects observed for cases with less than about 40% inoperative elements. However, for 50% inoperatives, the reduction in angular horizontal coverage approached 10%, which is significant in operation, since it could cause an effective "blind" spot.

C. Convergence Zone Mode (CZ)[13]

The convergence zone mode employs wide beam transmission at any one of three depression angles - followed immediately by an ODT in the horizontal plane (CZ-ODT). To form the beam, 24 adjacent staves are driven in-phase over a 120° azimuthal arc, and the resultant beam is henceforth referred to as a 120° beam.

Those criteria by which the bottom bounce transmission patterns were judged may also be employed for the convergence zone transmission beam patterns. The redundancy report[14] data on source level degradation, degradation at the pattern edge ($\pm 60^{o}$),

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[13] Signals transmitted in the convergence zone mode are presented on the A-scan display when received.

[14] See footnote 1.

and interior valley degradation are presented in Figure 24. The source level, averaged over the 120° width of the beam, has a degradation curve like those for the other modes of transmission. The source level is down about 6-1/2 dB when 50% of the transducer elements (and/or power amplifiers) have become inoperative.

The degradation at the pattern edge is much greater for CZ transmission than for BB transmission - varying from about 8-1/2 dB to more than 20 dB below the peak intensity of the all-elements-active array. (There is a good chance that at least one edge of the pattern will be degraded more than the deepest interior valley.) This means that the beam is effectively narrower than the nominal 120°. Examination of Figure 25, which shows the angular width of edge and valley degradations, reveals that at the standard -6 dB point, the CZ transmission beam (for all-elements-active) is only 111.5° wide (120-8.5°). By the time 48% of the elements have become inactive, the beam width (at -6 dB from the 48% peak) has been reduced to 90°.

The degradation of the deepest interior "valley" is again a strong function of the percentage of inoperative elements, and approaches 20 dB below the all-elements-active peak intensity for 50% inoperative elements. However, examination of Figure 25 reveals that for 48% inactive elements, only 5% of the 120° sector of ocean (a 6° sector) receives acoustic power degraded more than 14 dB below the all-elements-active peak power. (This compares with 8% for BB transmission.) Thus a smaller percentage of the horizontal sector is not properly ensonified in CZ as compared with BB.

The level of the highest sidelobe relative to the pattern peak has been plotted in Figure 26. The sidelobes were at a lower level than in the BB transmission, and in any case are relatively insignificant.

In summary, the source level was degraded as usual in the CZ transmission mode - about 1 dB per 8% inoperative elements

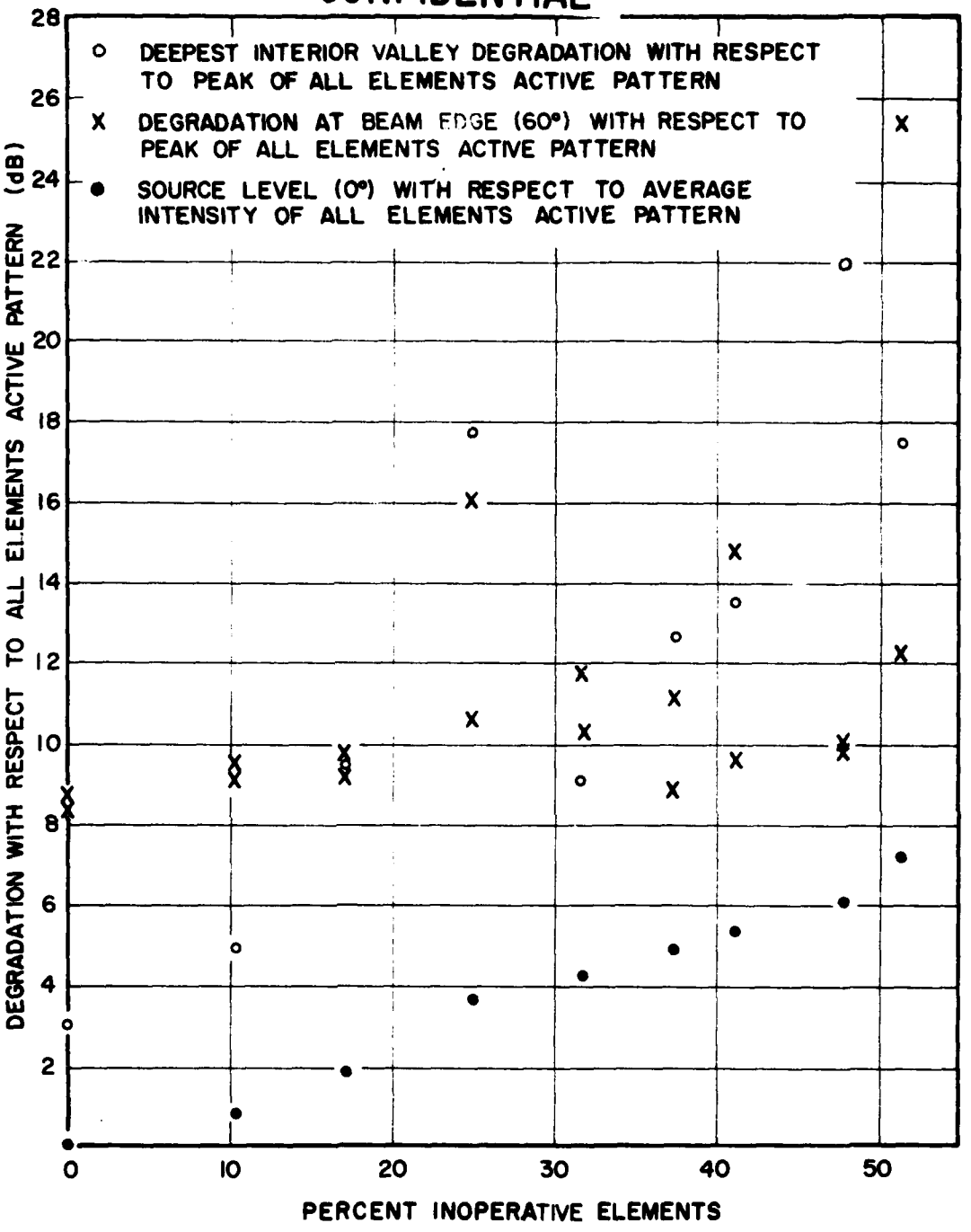

Fig.24-DEGRADATION OF 120° CONVERGENCE ZONE TRANSMISSION BEAM WITH RANDOM INOPERATIVE ELEMENTS; 0° TILT ANGLE ; 3.5 KC

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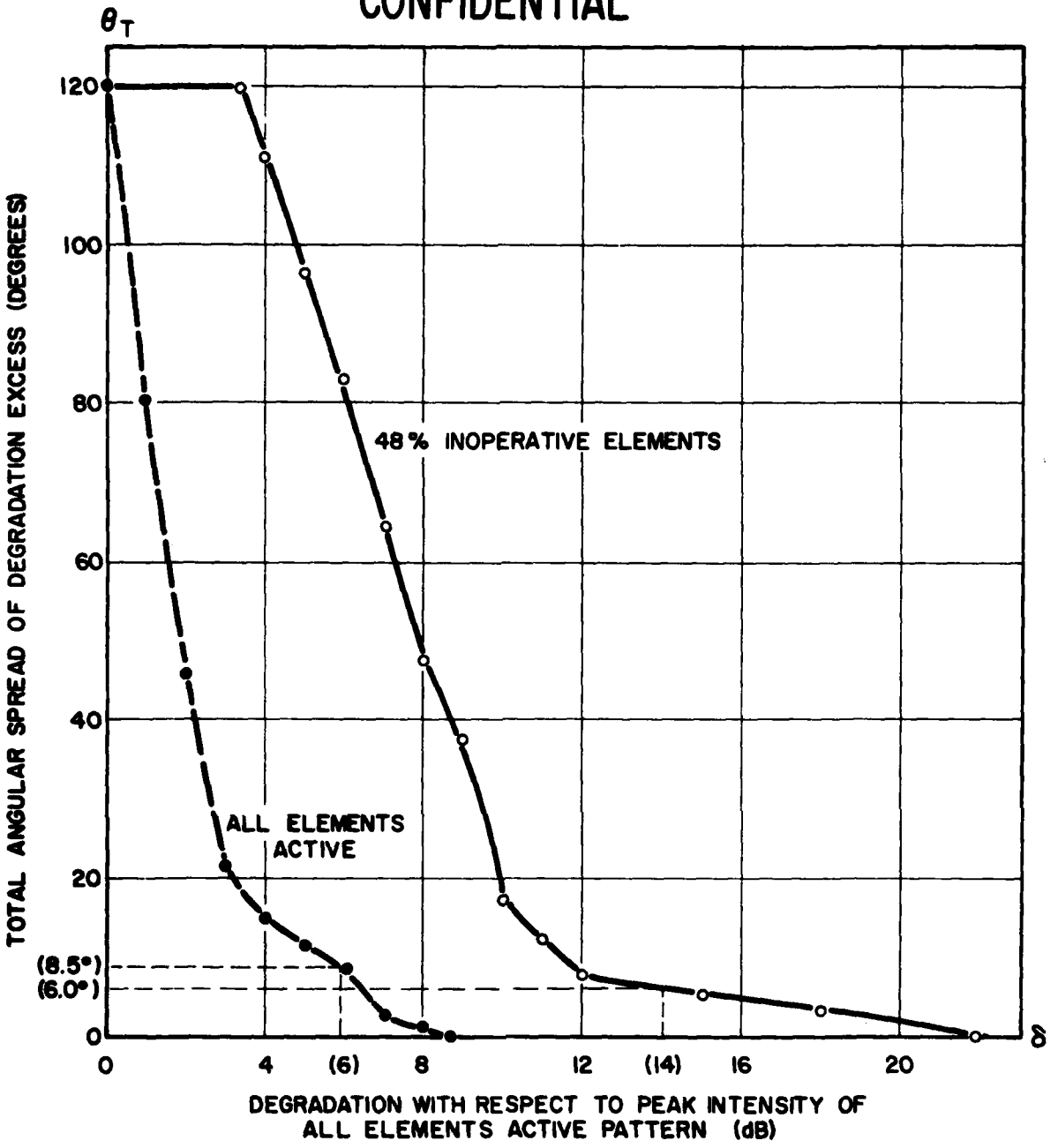

Fig 25- PROFILE OF TOTAL BEAM PATTERN VALLEY WIDTH FOR DIFFERENT LEVELS OF DEGRADATION; CONVERGENCE ZONE TRANSMISSION; 120° BEAM WIDTH; 0° TILT ANGLE; 3.5 KC

TRACOR, INC DWG A769-29
AUSTIN, TEXAS 11-4-64 STK-LBH

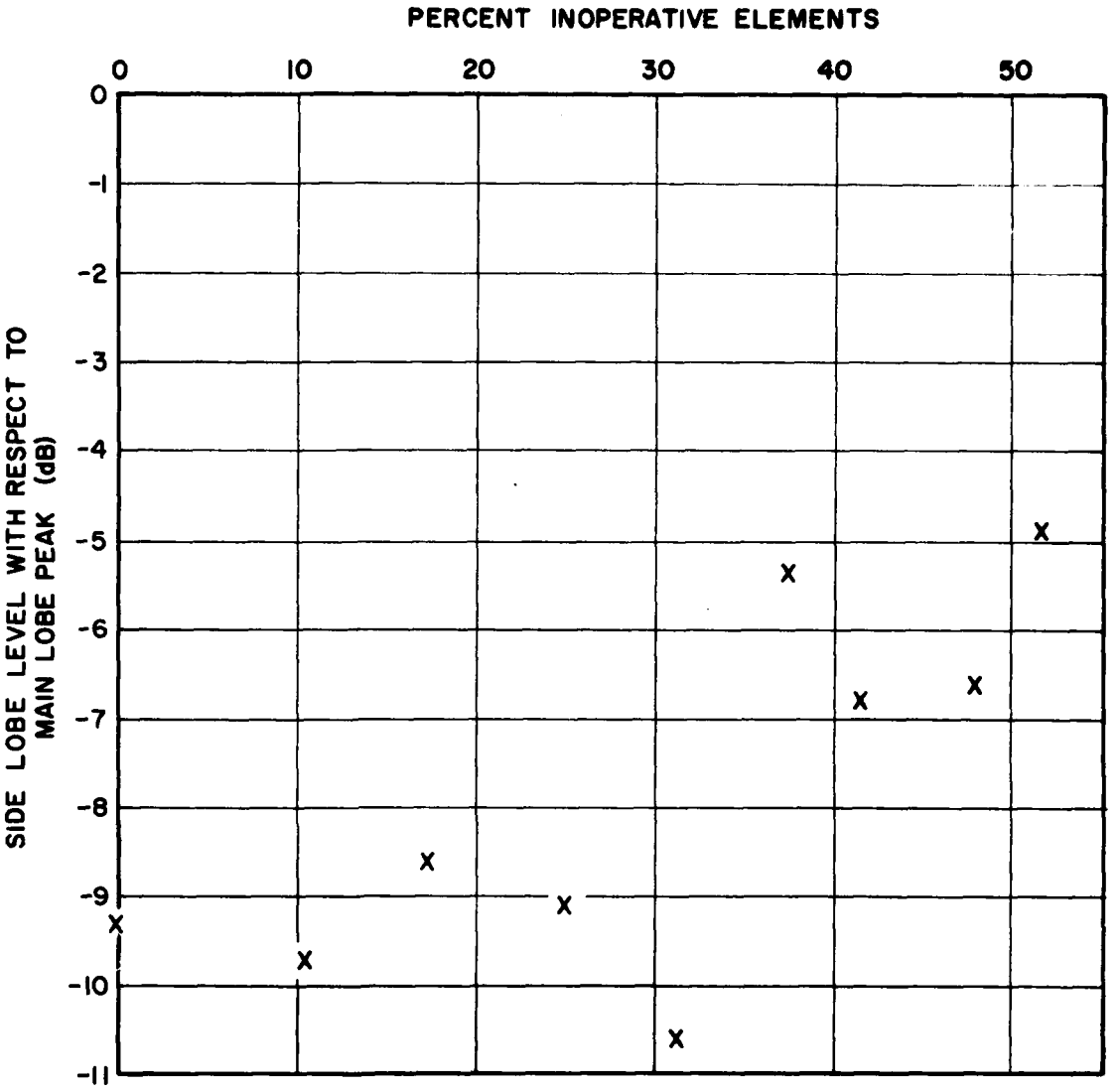

Fig.26- SIDE LOBE LEVEL FOR TRANSDUCERS WITH RANDOM INOPERATIVE ELEMENTS

CONVERGENCE ZONE TRANSMISSION; 120° BEAM WIDTH; 0° TILT ANGLE; 3.5 KC

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with the attendant decrease in horizontal area coverage. The interior valleys were deeper in CZ than in BB transmission, but were a smaller percentage of the sector. The edge degradation was significantly greater than in the BB transmission beams, resulting in an effective narrowing of the CZ beam. The all-elements-active beam is about 111.5° wide at -6dB, and this width decreases as the percentage of inoperative elements increases.

D. Summary of Transmit Modes

To conclude this section on the effects of redundant failures on the transmission performance of an AN/SQS-26 sonar equipments, the following points are re-emphasized:

(1) When transducer elements and/or power amplifiers fail, there will be a decrease in the source level which can not (in a cavitation limited transducer) be corrected by driving power adjustment due to the onset of cavitation. In all modes of transmission, the computed source level is degraded roughly 1 dB for each 8% inoperative transducer elements or power amplifiers in the 0% to 50% inoperative range. The computed degradations would result in reductions of horizontal area coverage down to about 25% of normal, for 50% inoperatives in the noise limited case. That is in this case, there is an effective loss in signal-to-noise ratio of 6 dB at the output of the horizontal beam former.

(2) There are no special problems in ODT or the continuously rotatable RDT. However in the stepwise RDT (Transmission at each 10°) case, the crossover point between major lobes is normally about -10 dB and increases as the number of inoperative transducer elements or power amplifiers increases. This effect could cause narrow blind spots in some cases, but in others normal ship course changes and yaw could cause the "hole" to be filled, since the RDT beam is not stabilized.

(3) In the 45° wide, bottom bounce transmission beam patterns, there was little significant pattern effect for less than 40% inoperative transducer elements or power amplifiers.

However, for greater than about 40% inoperative, rather large "holes" or "valleys" developed in the pattern, reducing the horizontal angular coverage by about 10% for 50% inoperatives.

(4) In the 120° wide, convergence zone beam patterns, the pattern degradation increased significantly as the number of inoperative elements approached 50%. With 48% inoperatives, the loss in horizontal angular coverage was computed to be only about 5% (half of BB). A significant point is that the computed CZ beam for all-elements-active is only about 111° wide instead of 120°.

IV. COMBINATION TRANSMIT, RECEIVE AND SIGNAL PROCESSING

The total effect of redundant failures on horizontal coverage is affected by both transmit and receive beam patterns and by the effect of signal processing on the formed beam electrical signals.

It would be very difficult to try to predict how the degradations in transmit would "fit" with those in receive, since the transducer elements are the only common cause of degradation. There should be no interdependence between failures of preamplifiers and power amplifiers.

In general, the combined degradation is controlled by the over all loss of source level in transmit and the "uncorrectable" variation in receiving sensitivity (though the latter is relatively small).

The effect of signal processing on total degradation can be analyzed through the use of Figure 27, which contains statistical curves obtained from a large amount of data processed by TRACOR under the SOFIX program[15]. These composite curves are for Gaussian noise and ideal signals for a linear correlator, clipped correlator and detector-averager.

At the output of the horizontal beam former, the beam is in the form of an electrical signal having some signal-to-noise ratio. This is the S/N input to the processor. The curves of Figure 27 show the average S/N output for a given S/N input for the three types of processors. Thus, by using the appropriate curve, one can determine the average change in $(S/N)_{out}$ for a change in $(S/N)_{in}$ from the slope of the curve. Inspection of the curves of Figure 27 reveals that the curve for the linear correlator has a slope only slightly greater than unity, so that any $\Delta(S/N)_{in}$ would result in

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[15] "Analysis of Signal Processing and Related Topics Pertaining to the AN/SQS-26 Sonar Equipment (U)," Confidential Summary Report, 27 March 1964, TRACOR, Inc., Contract NObsr-91039. TRACOR Document Number 64-146-C, (see Figure 2.3-7).

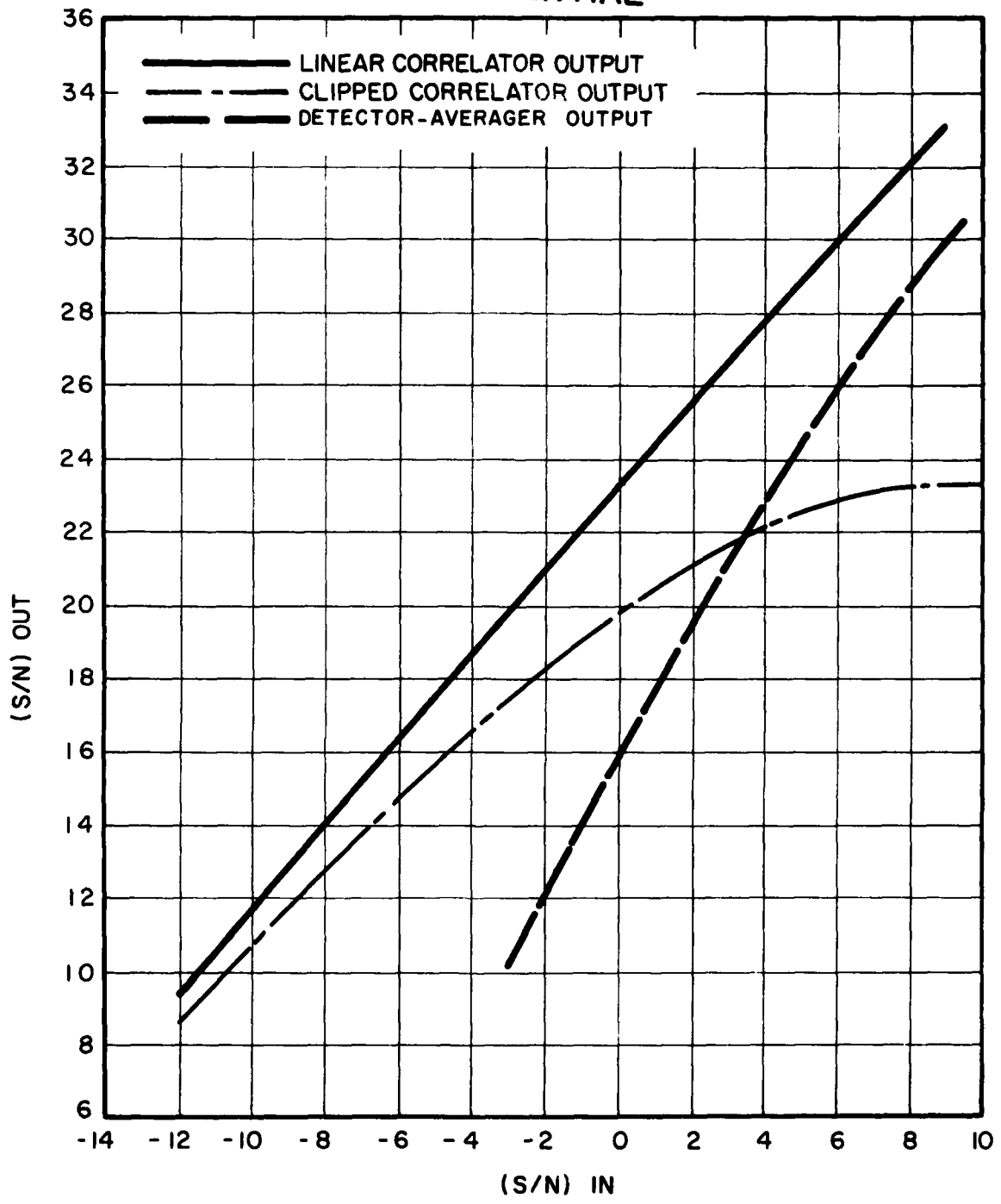

Fig. 27 - COMPOSITE CURVE - GAUSSIAN NOISE, IDEAL SIGNALS

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essentially the same $\Delta(S/N)_{out}$. The slope of the curve for the clipped correlator varies from unity at very small $(S/N)_{in}$ to almost zero for large $(S/N)_{in}$. Thus, in most of the practical cases using the clipped correlator, the $\Delta(S/N)_{out}$ would be less than the $\Delta(S/N)_{in}$. The only case in which the output change would be greater than the input change is for small $(S/N)_{in}$ using the detector-averager, since the slope there is two. In that case, any degradation in $(S/N)_{in}$ would be effectively doubled. However, as the $(S/N)_{in}$ increases, the slope approaches unity, where the changes would be unaffected as they pass through the detector-averager.

In summary, only the detector-averager will tend to amplify S/N ratio degradations, and then only at small input signal-to-noise ratios. In contrast, degradations are reduced in the clipped correlator for large signal-to-noise inputs. The linear correlator leaves the degradations essentially unaffected as signals pass through it.

V. SUMMARY AND CONCLUSIONS

This work was entirely computational in nature and did not involve any actual measurements. The beam pattern computations were based on the assumption of constant pressure sources, with no element interaction. The conclusions drawn here are based primarily on relative values of the various parameters with respect to the all-elements-active cases. Only sidelobe levels were judged on an absolute value basis.

From the TRACOR beam pattern computations, the following conclusions can be drawn with regard to horizontal coverage of the AN/SQS-26 sonar equipments:

RECEIVE

(1) The receiving sensitivity decreases with an increasing number of inoperative transducer elements, preamplifiers, or staves (see INTRODUCTION). However, most of the sensitivity degradation due to randomly located failures can be compensated for by over all gain adjustment. Only in extremely quiet conditions would amplifier gain limit this adjustment.

(2) There is some statistical variation in sensitivity to be expected around the transducer due to nonuniform distribution of inoperative elements or staves. For up to 50% inoperative elements, this variation is generally less than 2.5 dB, which is within the practical limits of adjustment of the display for optimum detection capability. In the case of up to 50% inoperative staves, the variation might exceed 5 dB and could have a significant effect on horizontal coverage.

(3) Sidelobe level degradation is significant in both inoperative element and inoperative stave cases. Although, this effect does not bear directly on horizontal coverage, erroneous target bearing indications are possible.

(4) Inoperative beams can probably be tolerated in the passive and B-scan modes (5° beam spacing) provided two adjacent beams are not inoperative. However a beam loss in A-scan (10° beam spacing) produces about a 10% loss in horizontal coverage and could not normally be tolerated in operation.

TRANSMIT

(5) When transducer elements and/or power amplifiers fail, there will be a decrease in the source level which cannot (in a cavitation limited transducer) be corrected by gain adjustment due to the onset of cavitation. In all modes of transmission, the computed source level is degraded roughly 1 dB for each 8% inoperative transducer elements or power amplifiers in the 0% to 50% inoperative range. The computed degradations would result in reductions of horizontal area coverage down to only 25% of normal, for 50% inoperatives in the noise limited case.

(6) There are no special problems in ODT or the continuously rotatable RDT. However in the stepwise RDT (transmission at each 10°) case, the crossover point between major lobes is normally about -10 dB and increases as the number of inoperative transducer elements or power amplifiers increases. This effect could cause narrow blind spots in some cases, but in others normal ship maneuvers could cause the "hole" to be filled, since the RDT beam is not stabilized.

(7) In the 45° wide, bottom bounce transmission beam patterns, there was little significant pattern effect for less than 40% inoperative transducer elements or power amplifiers. However, for greater than about 40% inoperative, rather large "holes" or "valleys" developed in the pattern, reducing the horizontal angular coverage by about 10%, for 50% inoperatives.

(8) In the 120° wide, convergence zone beam patterns, the pattern degradation increased significantly as the number of inoperative elements approached 50%. With 48% inoperatives, the loss in horizontal angular coverage was computed to be only about 5% (half of BB). A significant point is that the computed CZ beam for all elements active is only about 111° wide instead of 120°.

TRANSMIT, RECEIVE and SIGNAL PROCESSING

(9) In general, the combined degradation is controlled by the over all loss of source level in transmit and the "uncorrectable" variation in receiving sensitivity.

(10) The detector-averager will tend to amplify degradations at small input signal-to-noise ratios, but leave them unaffected at large signal-to-noise ratios.

(11) Degradations are reduced in the clipped correlator for large signal-to-noise inputs, and are unaffected at low signal-to-noise inputs.

(12) The linear correlator leaves the degradations essentially unaffected as signals pass through it, for any signal-to-noise input.

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LIST OF PERSONNEL

The following TRACOR personnel, listed in alphabetical order, worked on this project:

Judy Clouser
R. D. Estes
H. L. Gray
G. T. Kemp
Alice Spitzer
J. R. Thompson
E. A. Tucker
A. F. Wittenborn

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APPENDIX A
Note on Conditional Probability

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APPENDIX A

NOTE ON PROBABILITY

Consider now the problem of determining the probability that a transducer has a total of x inoperative staves and y inoperative staves in an array of M staves selected at random. Let P[A,B] and P[A:B] denote respectively the probability of A and B, and the probability of A, given B.

Let N = total number of staves in the transducer and

$P[x/N, y/M]$ = probability x of the N staves and y of some array (selected at random) of M staves are inoperative at time t. (1)

Let the subscripts R, T, and RT respectively when placed on (1) denote inoperative receive, inoperative transmit, and inoperative both transmit and receive. For example

$P[x/N, y/M]_R$ = probability x of the N staves and y of some array (selected at random) of M staves are inoperative in the receive mode at time t.

Now,

$$P[x/N, y/M] = P[x/N] \cdot P[y/M:x/N] \tag{2}$$

Hence it becomes necessary to compute P[x/N] and P[y/M:x/N]. Consider then the following:

$$P[x/N]_R = \binom{N}{x} \left[P_{SR}(t)\right]^x [1 - P_{SR}(t)]^{N-x} \tag{3}$$

$$P[x/N]_T = \binom{N}{x} \left[P_{ST}(t)\right]^x \left[1 - P_{ST}(t)\right]^{N-x} \quad (4)$$

$$P[x/N]_{RT} = \binom{N}{x} \left[P_{SRT}(t)\right]^x \left[1 - P_{SRT}(t)\right]^{N-x} \quad (5)$$

where $P_{SR}(t)$, $P_{ST}(t)$, $P_{SRT}(t)$ are defined as follows:

$P_{ST}(t)$ = probability that a stave in transmit is inoperative at time t.

$P_{SR}(t)$ = probability that a stave in receive is inoperative at time t.

$P_{SRT}(t)$ = probability that a stave in transmit and receive is inoperative at time t.

Now, it will be assumed that the power amplifiers are all equally likely to be inoperative at time t and that their failures are independent. Moreover the same assumption will be made for transducer elements, preamplifiers, and post-amplifiers. Then let

$P_{pa}(t)$ = probability that a power amplifier is inoperative at time t.

$P_e(t)$ = probability that a transducer element is inoperative at time t.

$P_{pr}(t)$ = probability that a preamplifier is inoperative at at time t.

$P_{po}(t)$ = probability that a post amplifier is inoperative at time t.

$$P_{ST}(t) = [P_{pa}(t) + P_e(t) - P_{pa}(t)\ P_e(t)]^8 \tag{6}$$

$$P_{SR}(t) = P_{po} + [P_{pr}(t) + P_e(t) - P_{pr}(t)\ P_e(t)]^8$$

$$- P_{po}\ [P_{pr}(t) + P_e(t) - P_{pr}(t)\ P_e(t)]^8$$

$$= P_{po}\left[1 - [P_{pr}(t) + P_e(t) - P_{pr}(t)\ P_e(t)]^8\right]$$

$$+ [P_{pr}(t) + P_e(t) - P_{pr}(t)\ P_e(t)]^8 \tag{7}$$

$$P_{STR}(t) = P_{po}(t)\ P_{ST}(t) + [P_e(t) + P_{pr}(t)\ P_{pa}(t) -$$

$$P_e(t)\ P_{pr}(t)\ P_{pa}(t)]^8$$

$$- P_{po}(t)\ P_{ST}(t)\ [P_e(t) + P_{pr}(t)\ P_{pa}(t) -$$

$$P_e(t)\ P_{pr}(t)\ P_{pa}(t)]^8 \tag{8}$$

Finally

$$P[y/M{:}x/N] = \frac{\binom{x}{y}\ \binom{N-x}{M-y}}{\binom{N}{M}} \tag{9}$$

Consequently if x and y are interpreted as the number of staves inoperative in transmit, receive, or both depending on which we wish to discuss, then (9) can be used for all three cases. Hence if $P_{pr}(t)$, $P_{po}(t)$, $P_{pa}(t)$ are known (1) can be found by using (9) and (3), (4), or (5) depending on whether one is considering receive, transmit, or both.

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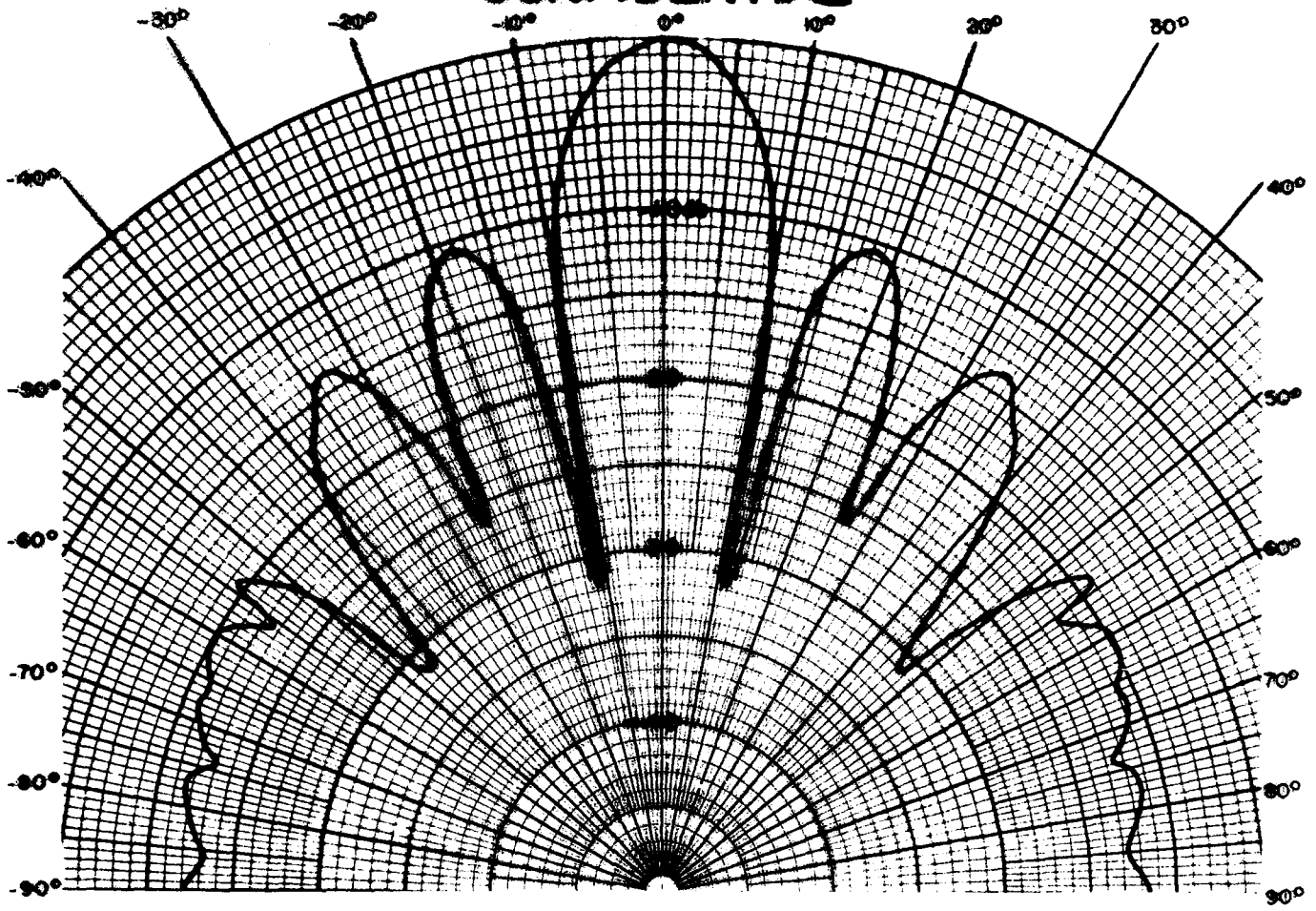
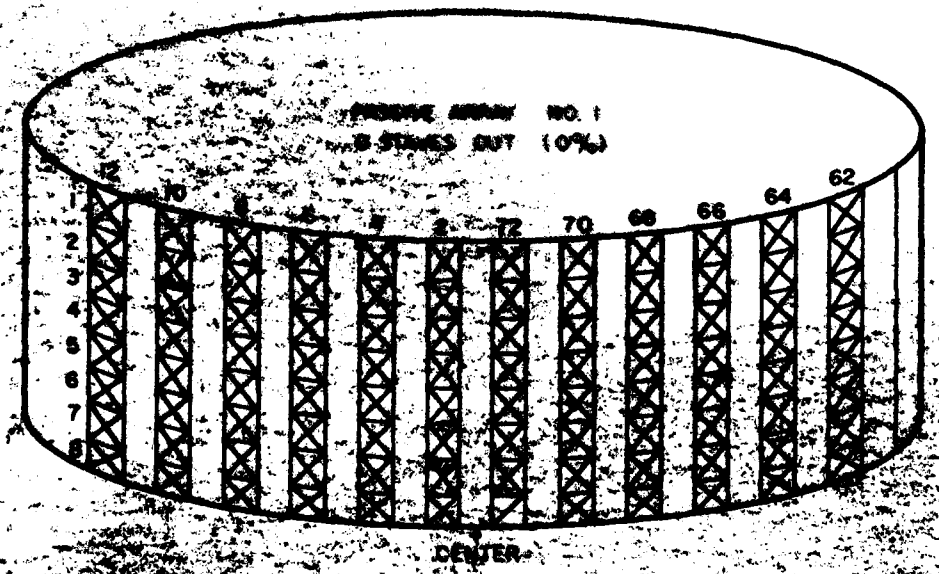
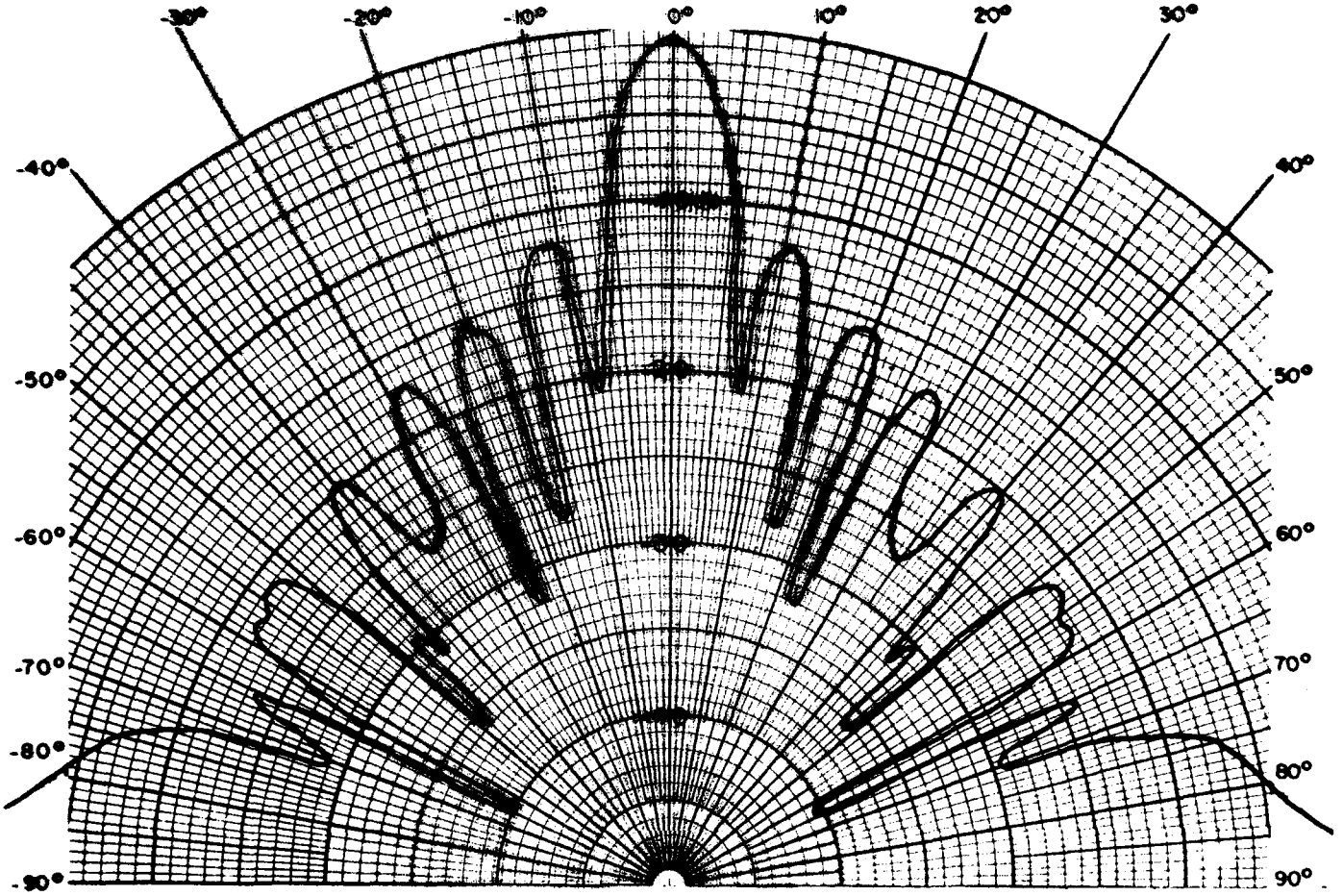
APPENDIX B
Passive Mode Beam Patterns



PASSIVE
f = 1.5 KC





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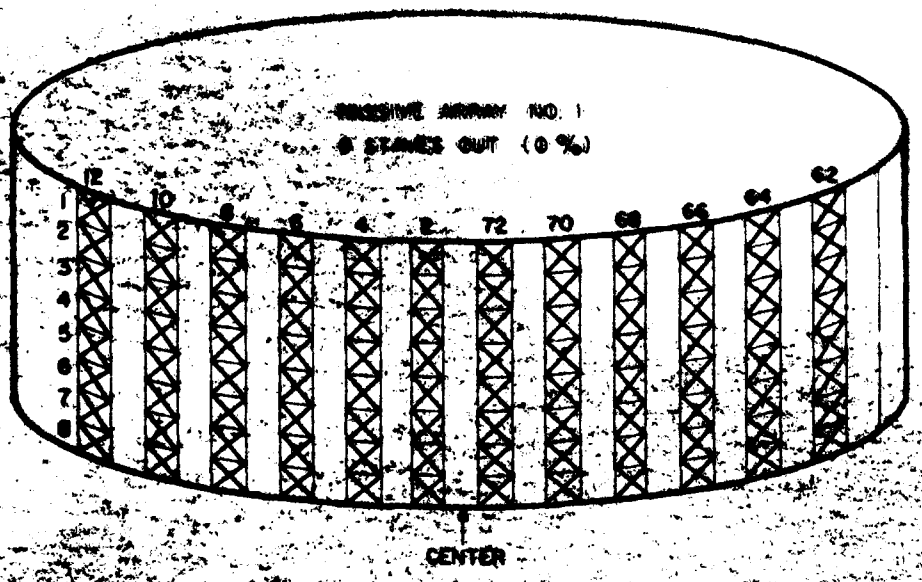
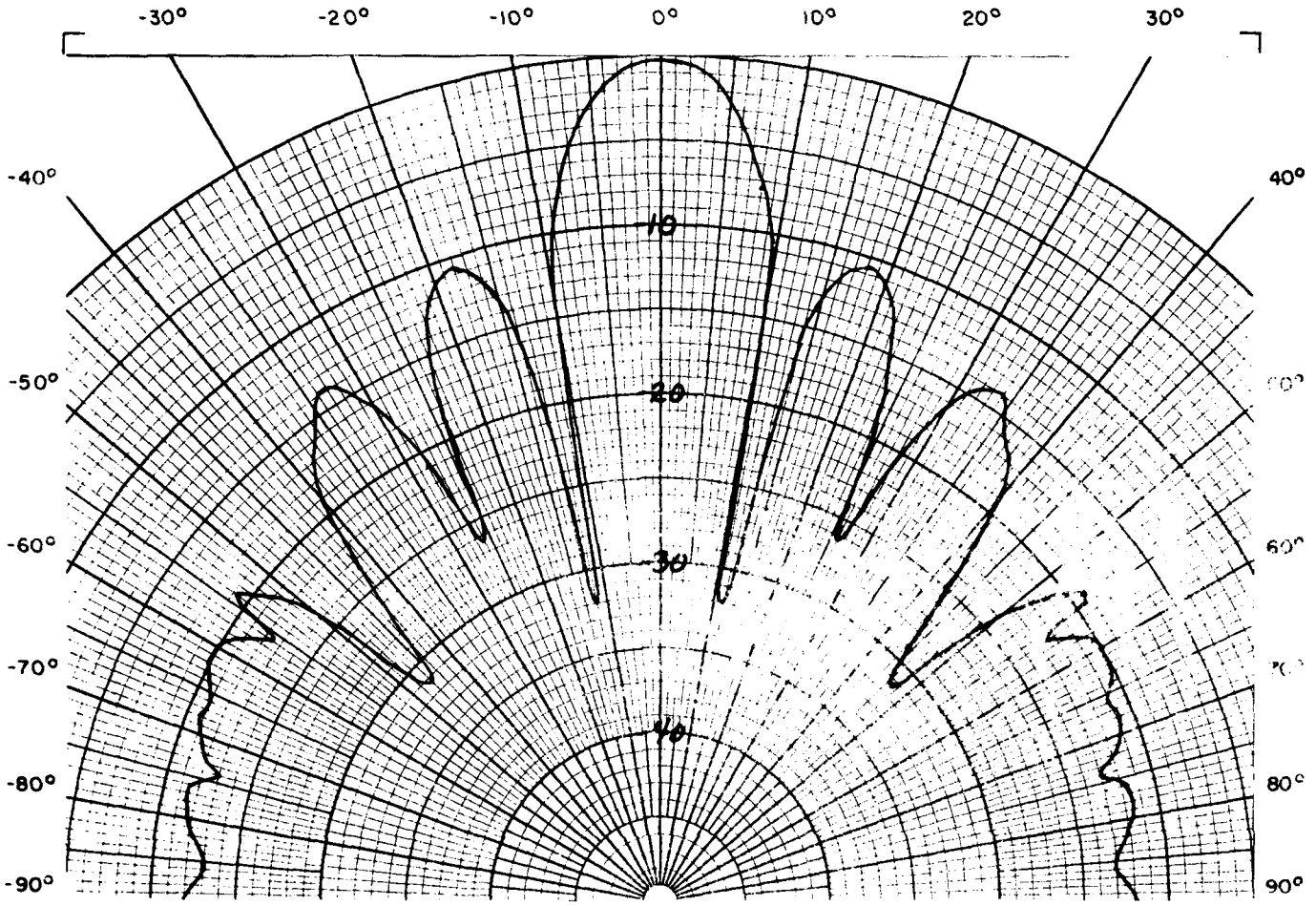
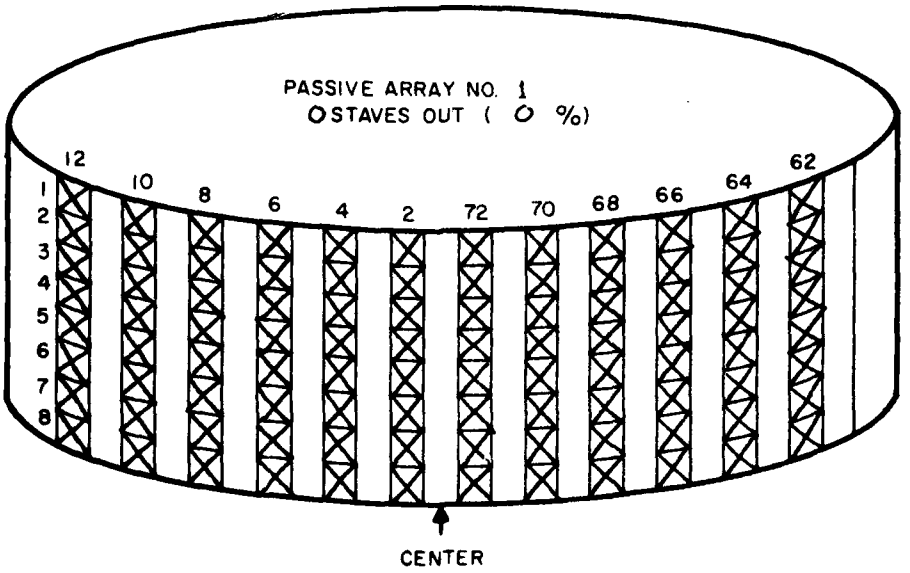


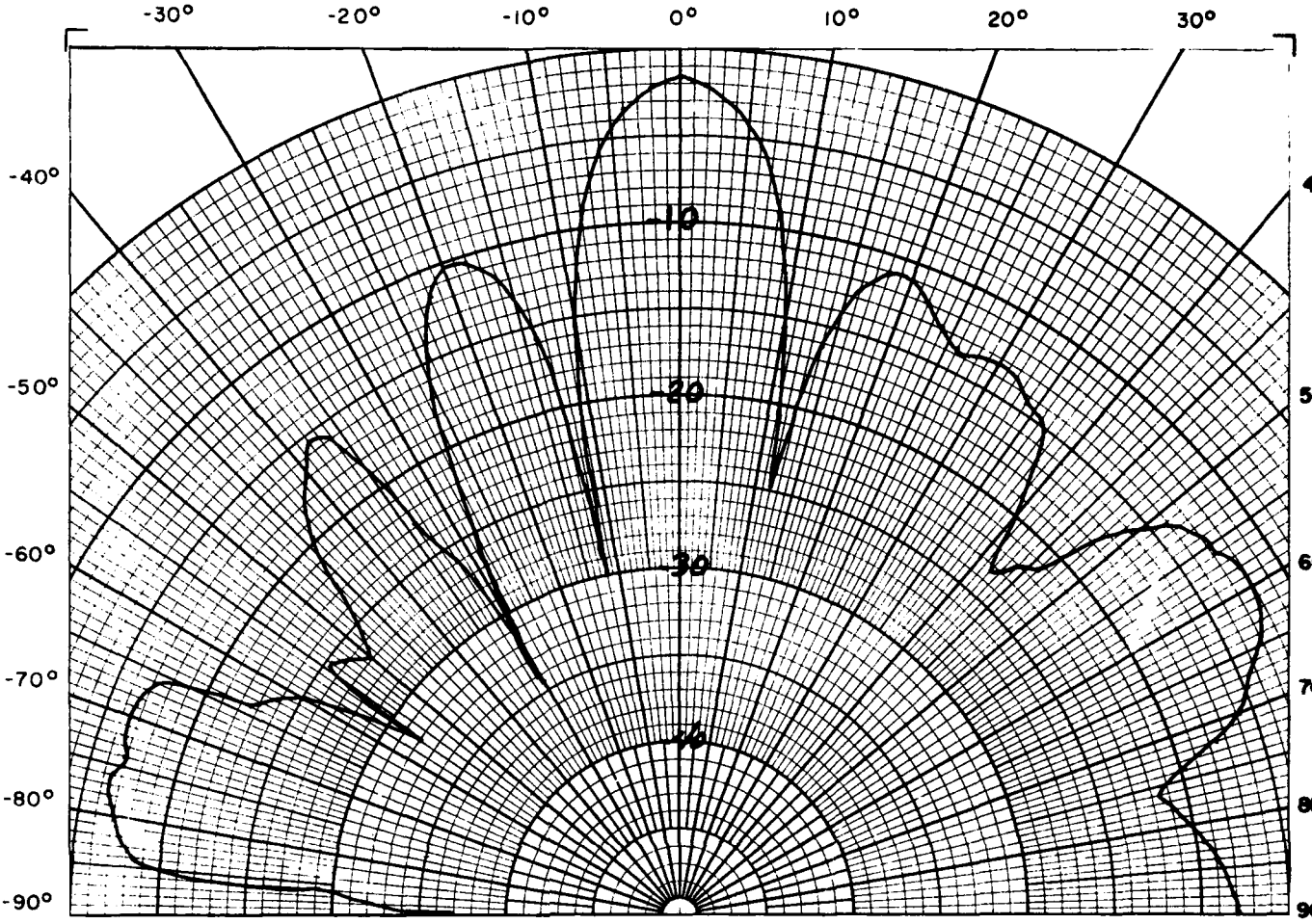


PASSIVE
f= 1.5 KC



B1

TRACOR, INC. DWG. A742-111
AUSTIN, TEXAS 3/23/64 GTK/CB



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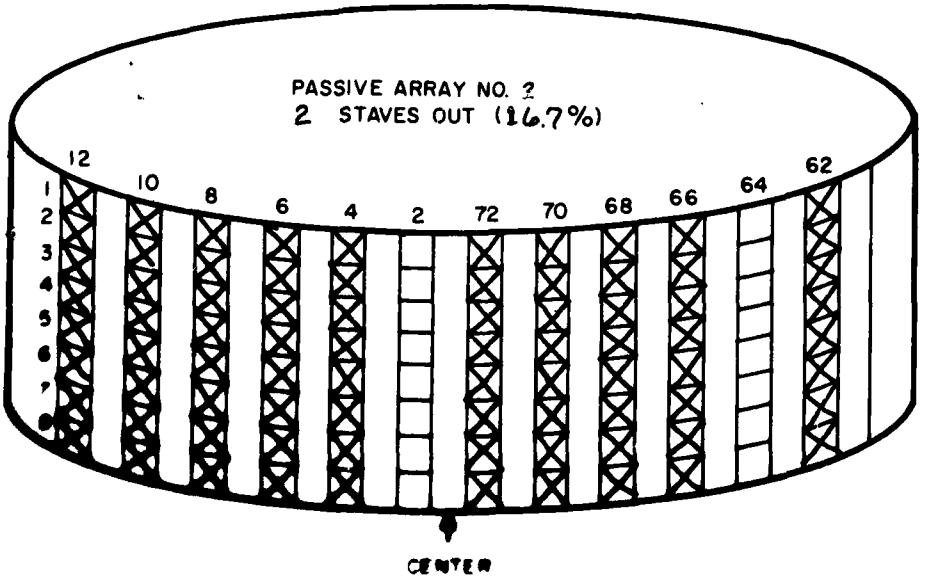
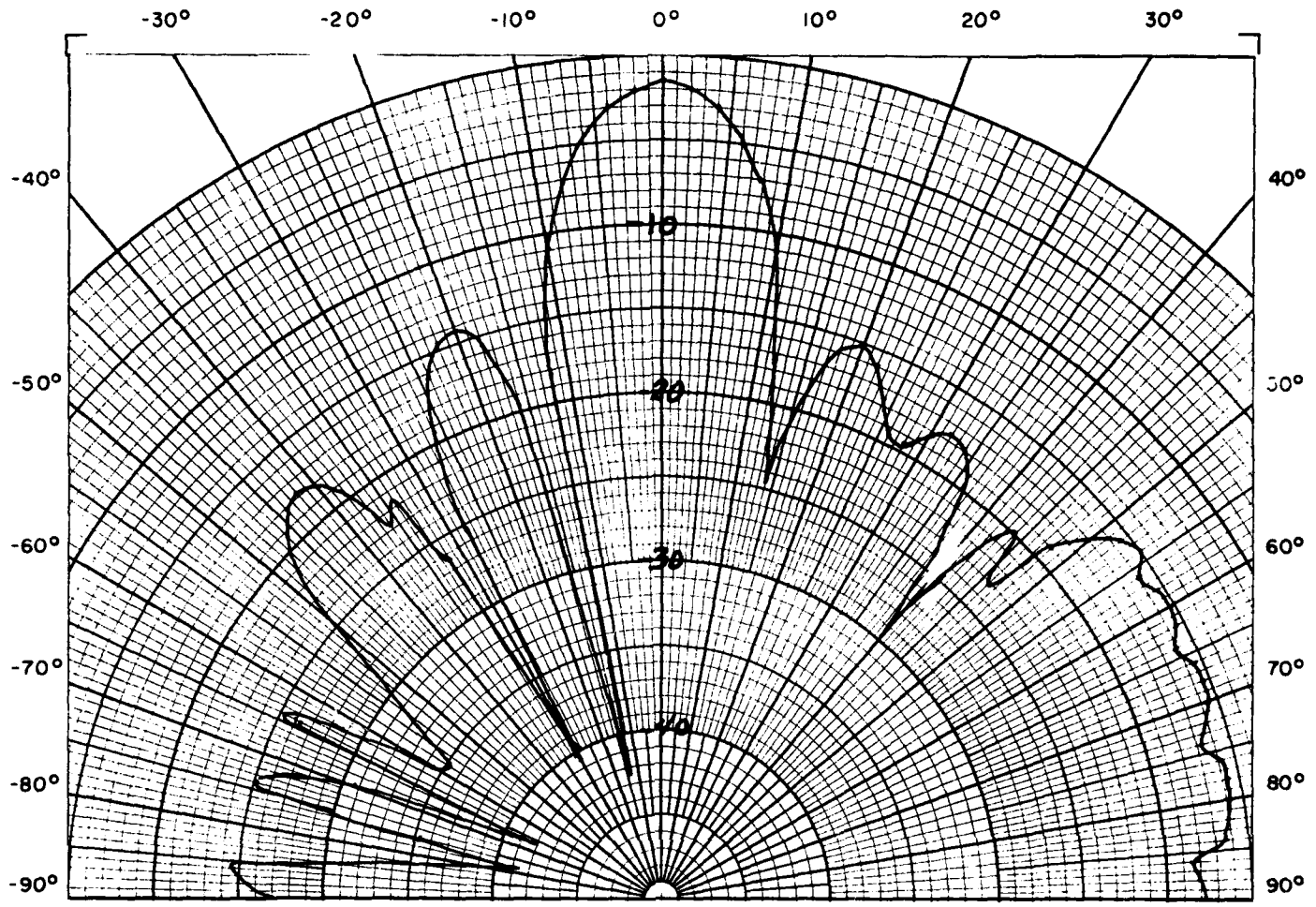


B2

TRACOR, INC. DWG A742-111
AUSTIN, TEXAS 3/23/64 GTK/CB



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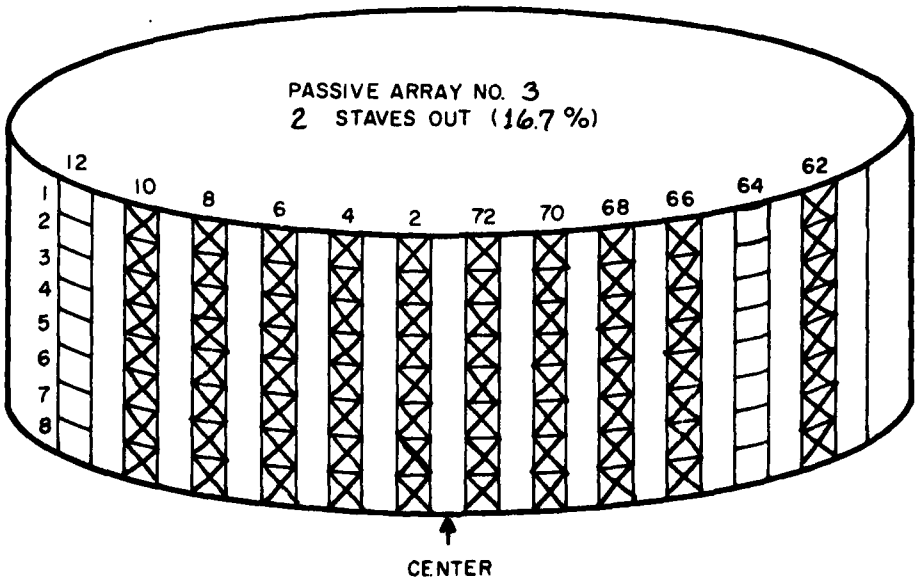
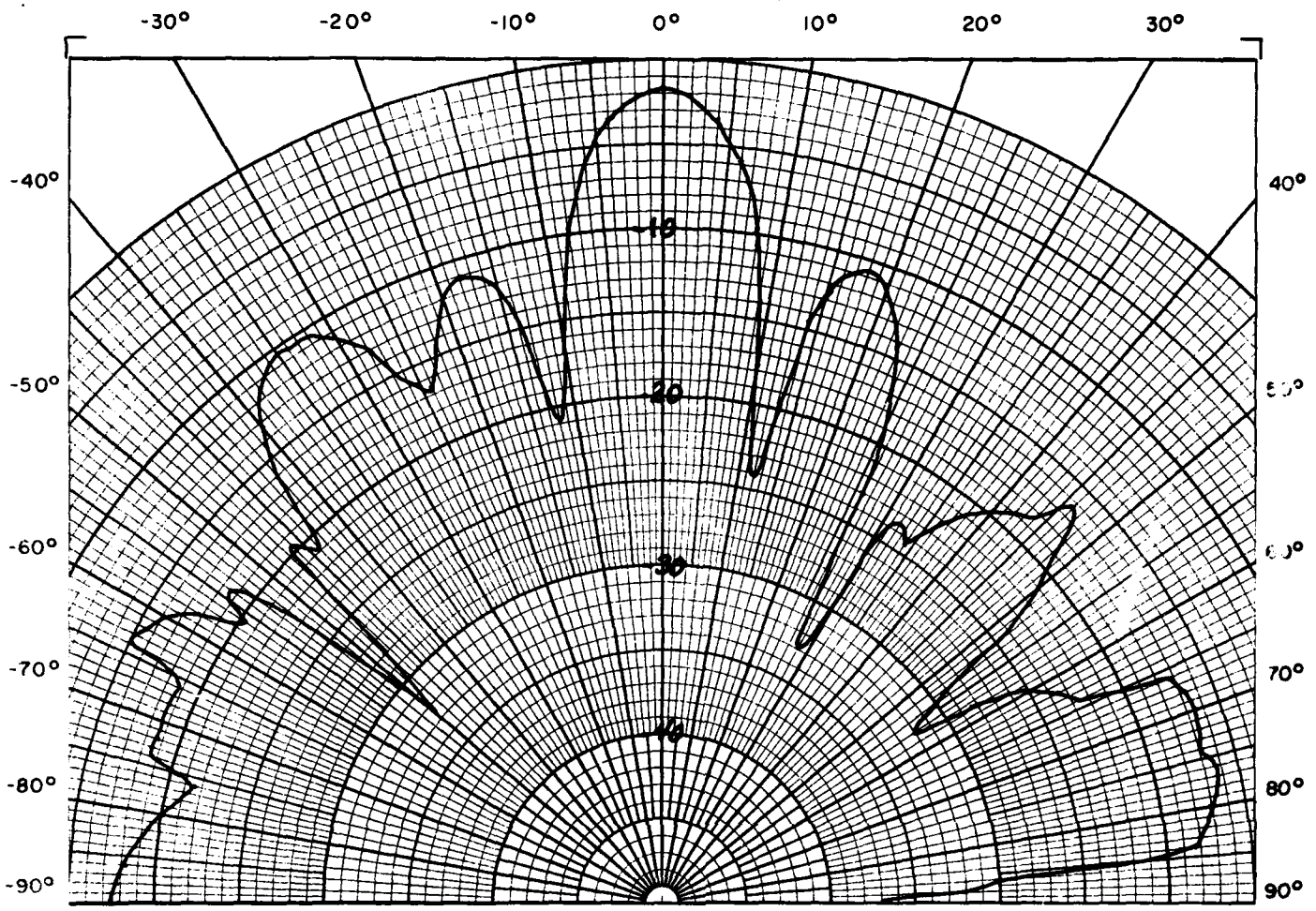


B3

TRACOR, INC. DWG. A742-III
AUSTIN, TEXAS 3/23/64 GTK/CB



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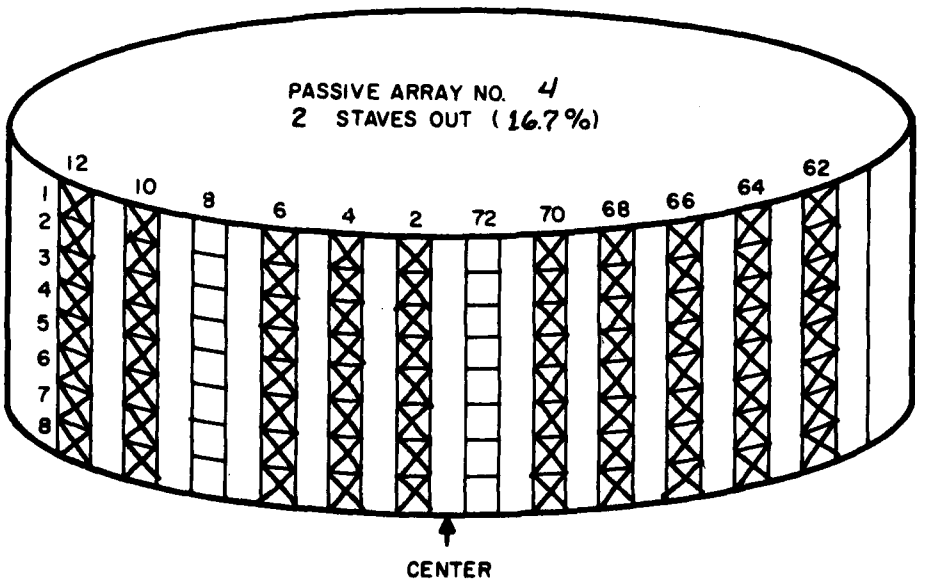
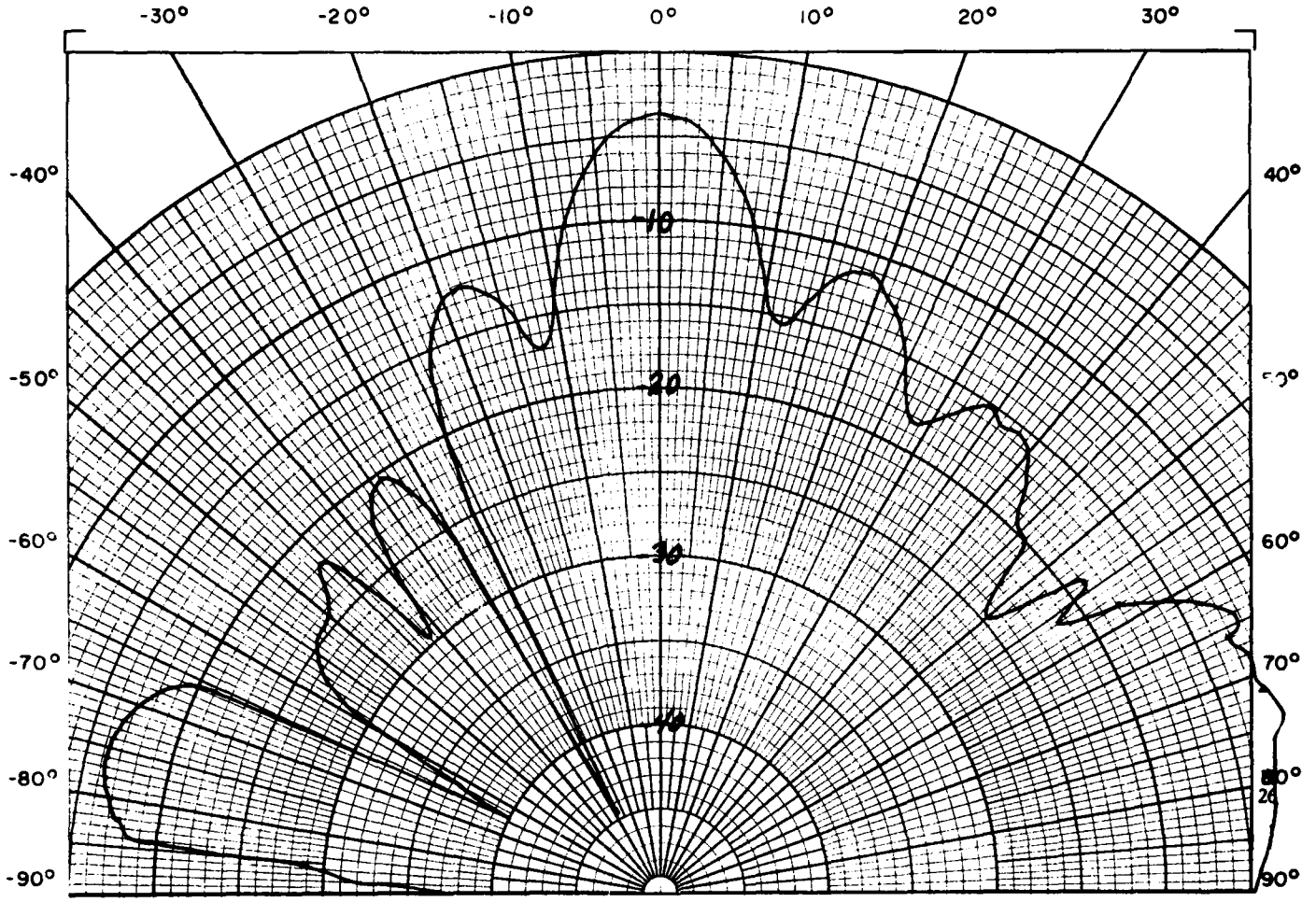


TRACOR, INC. DWG. A742-111
AUSTIN, TEXAS 3/23/64 GTK/CB



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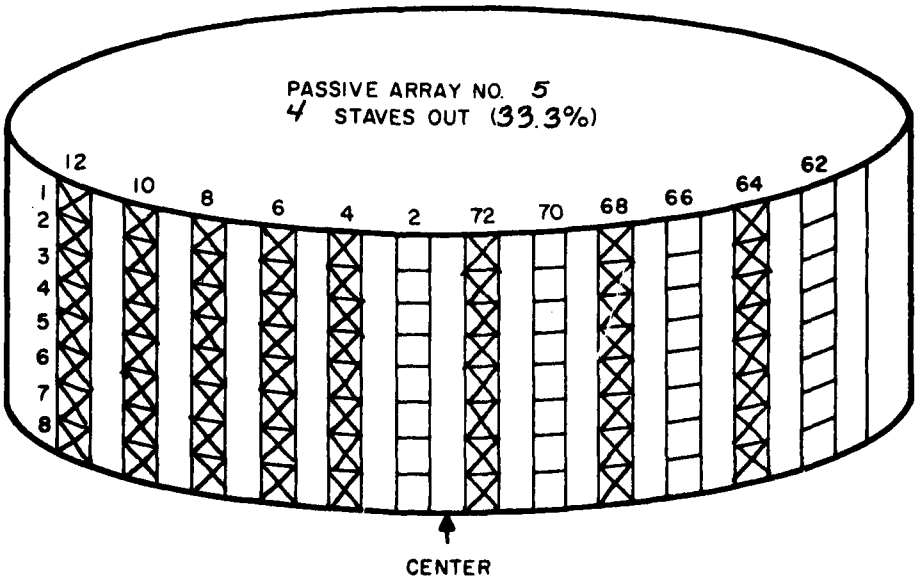
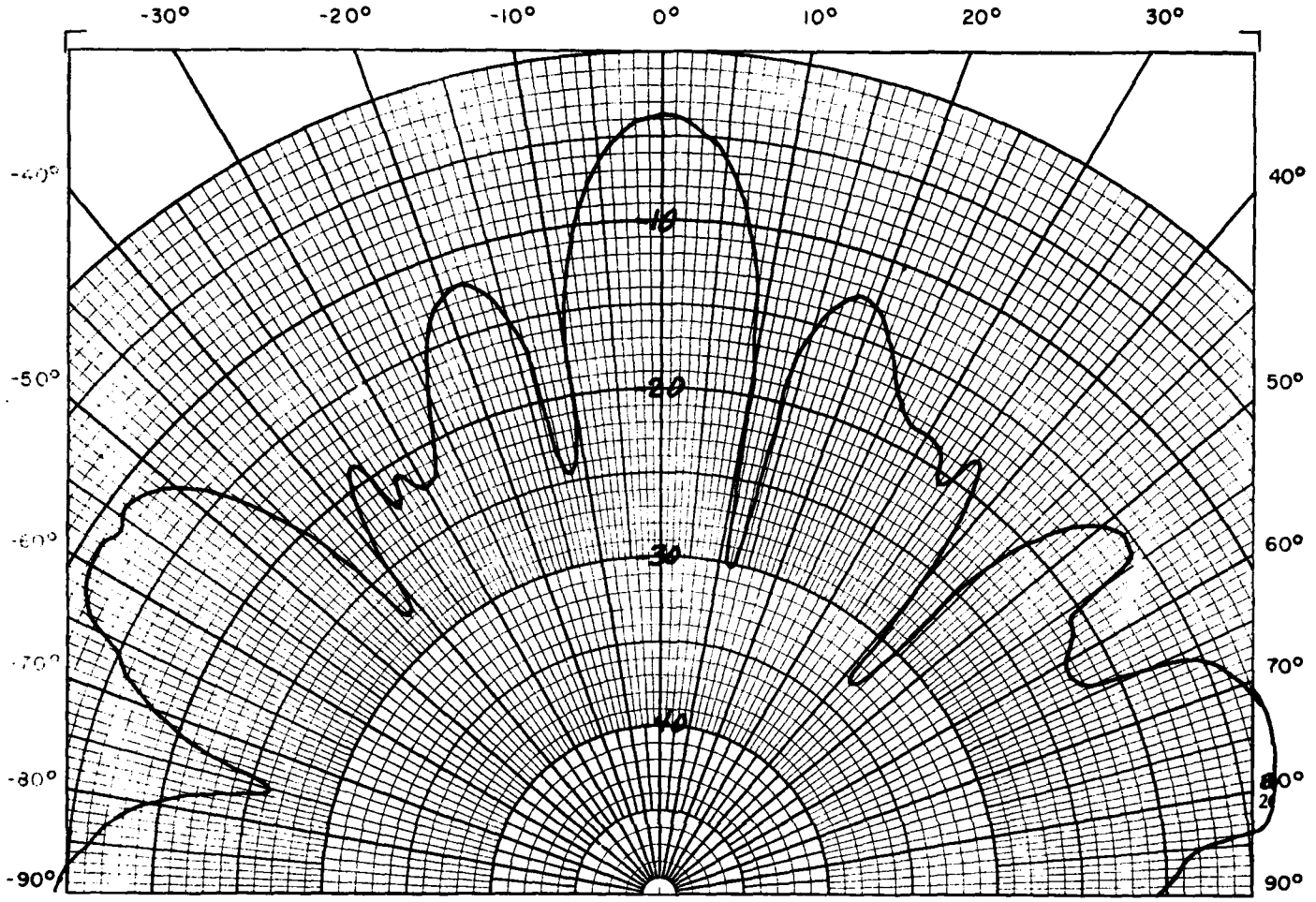


B5

TRACOR, INC DWG. A742-111
AUSTIN, TEXAS 3/23/64 GTK/CB



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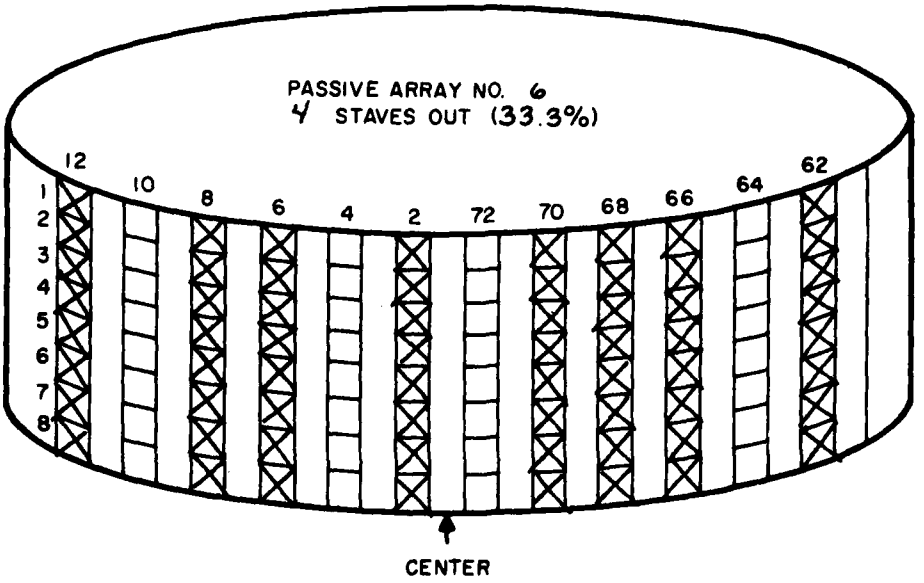
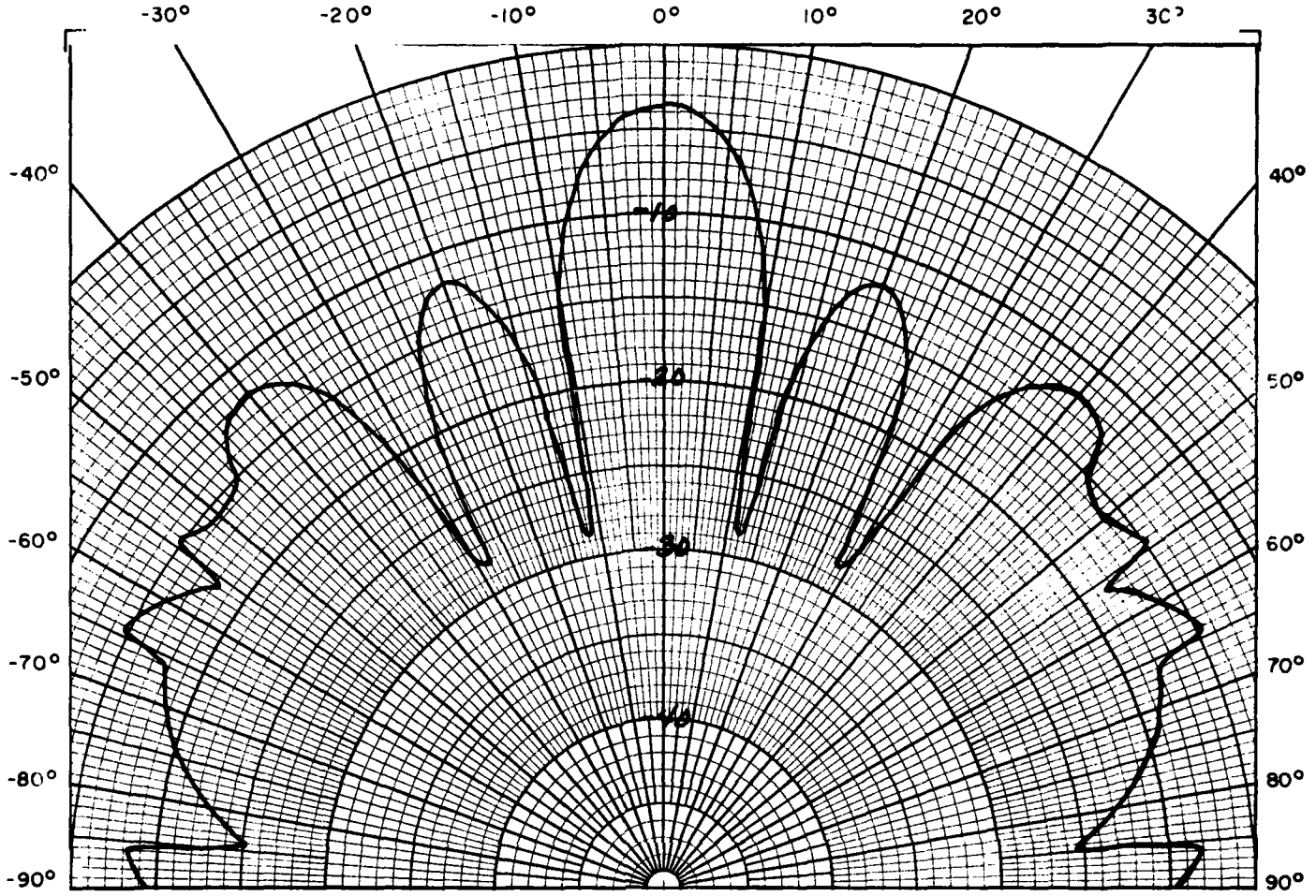


B6

TRACOR, INC. DWG. A742-111
AUSTIN, TEXAS 3/23/64 GTK/CB



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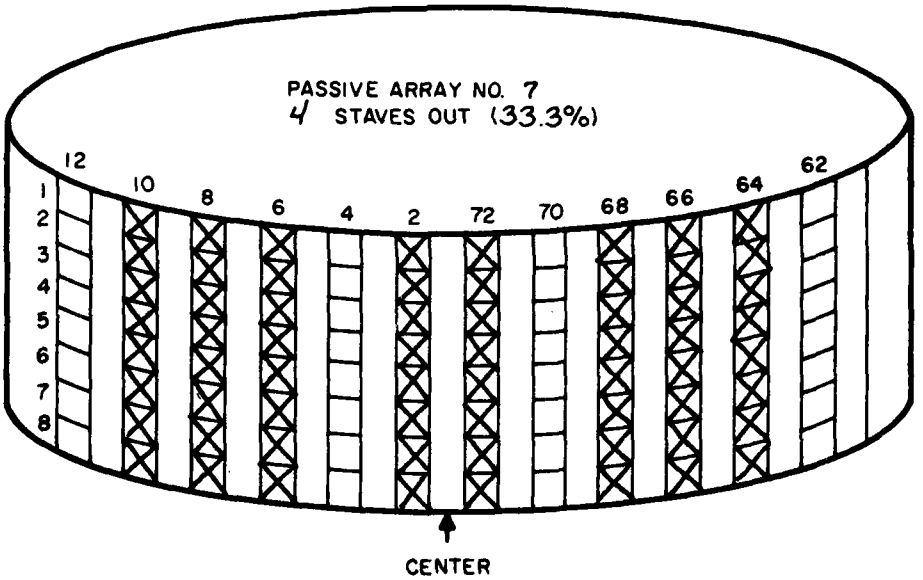
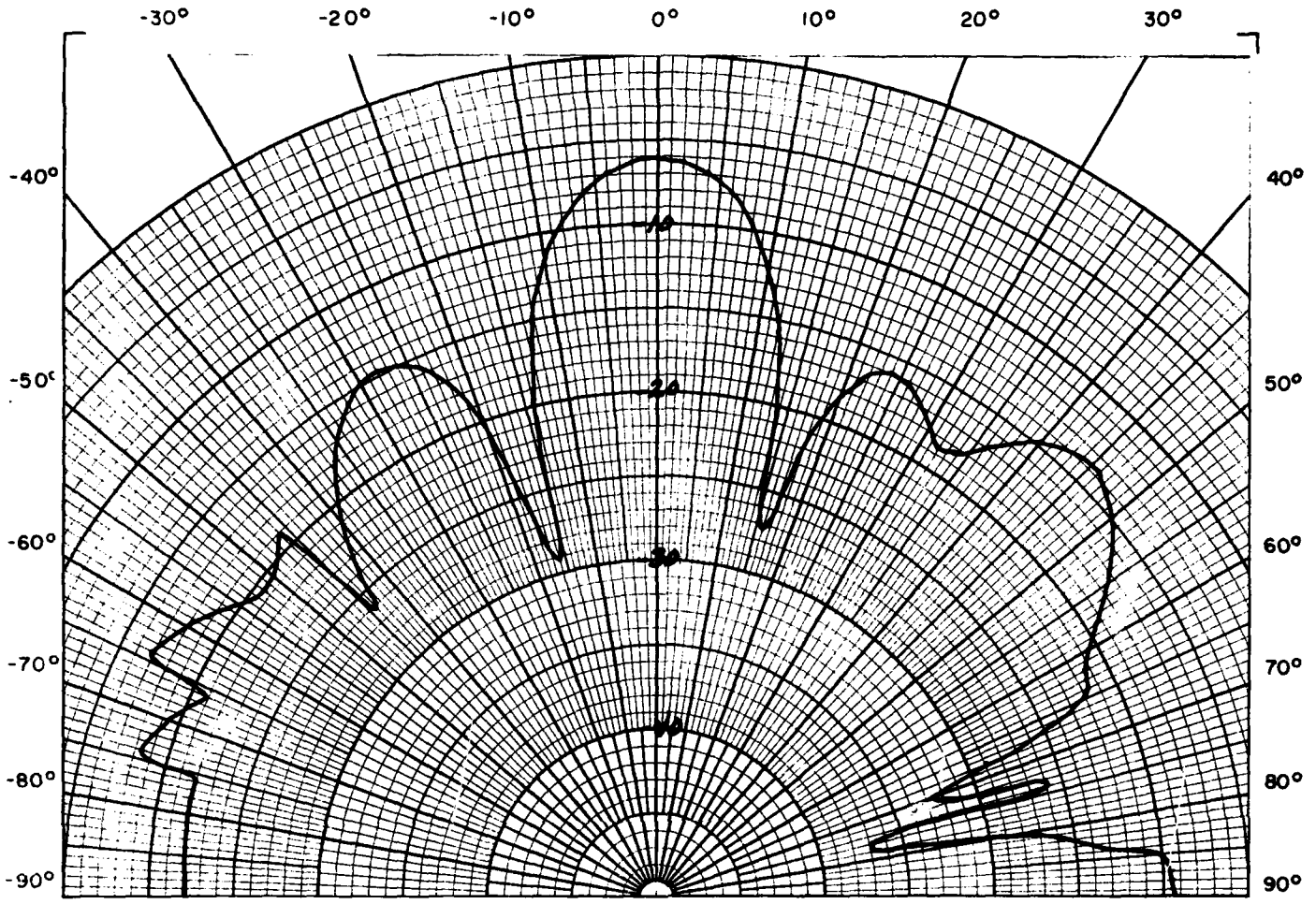


B7

TRACOR, INC. DWG. A742-111
AUSTIN, TEXAS 3/23/64 GTK/CB



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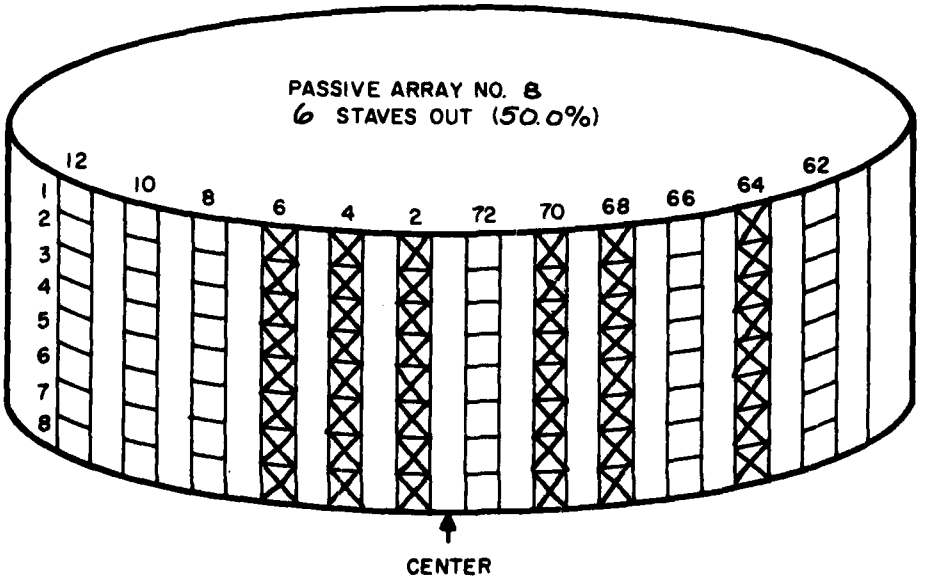
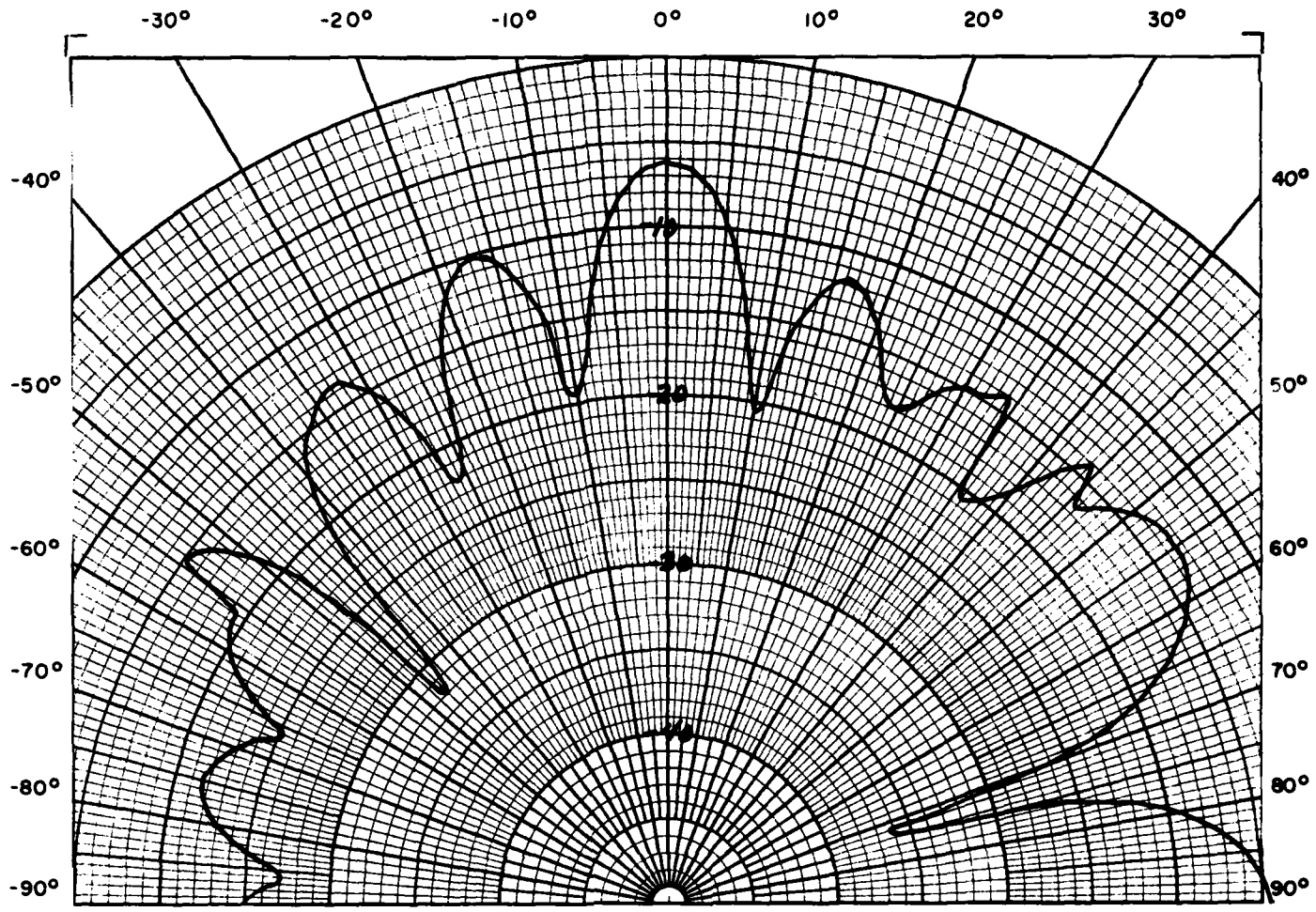


B8

TRACOR, INC. DWG. A742-111
AUSTIN, TEXAS 3/23/64 GTK/CB



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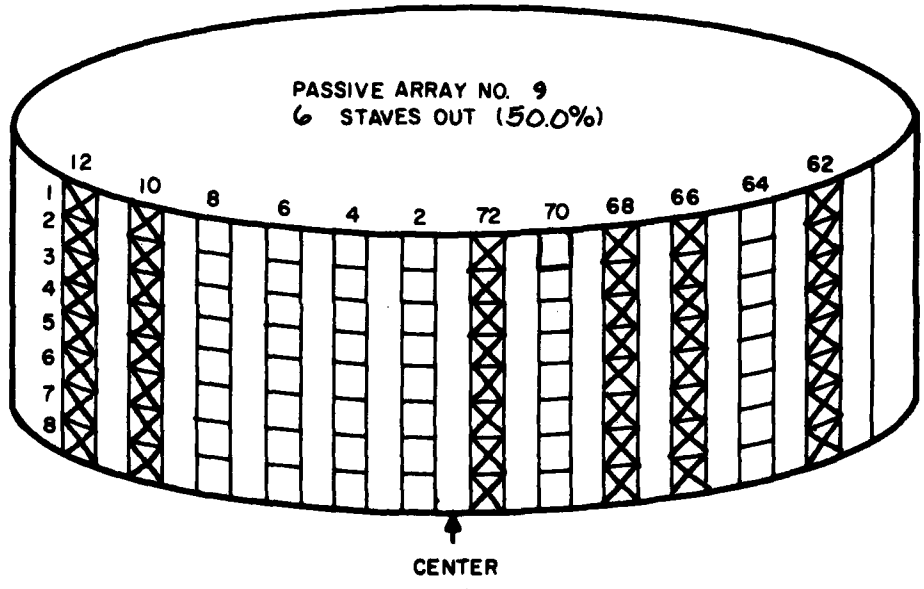
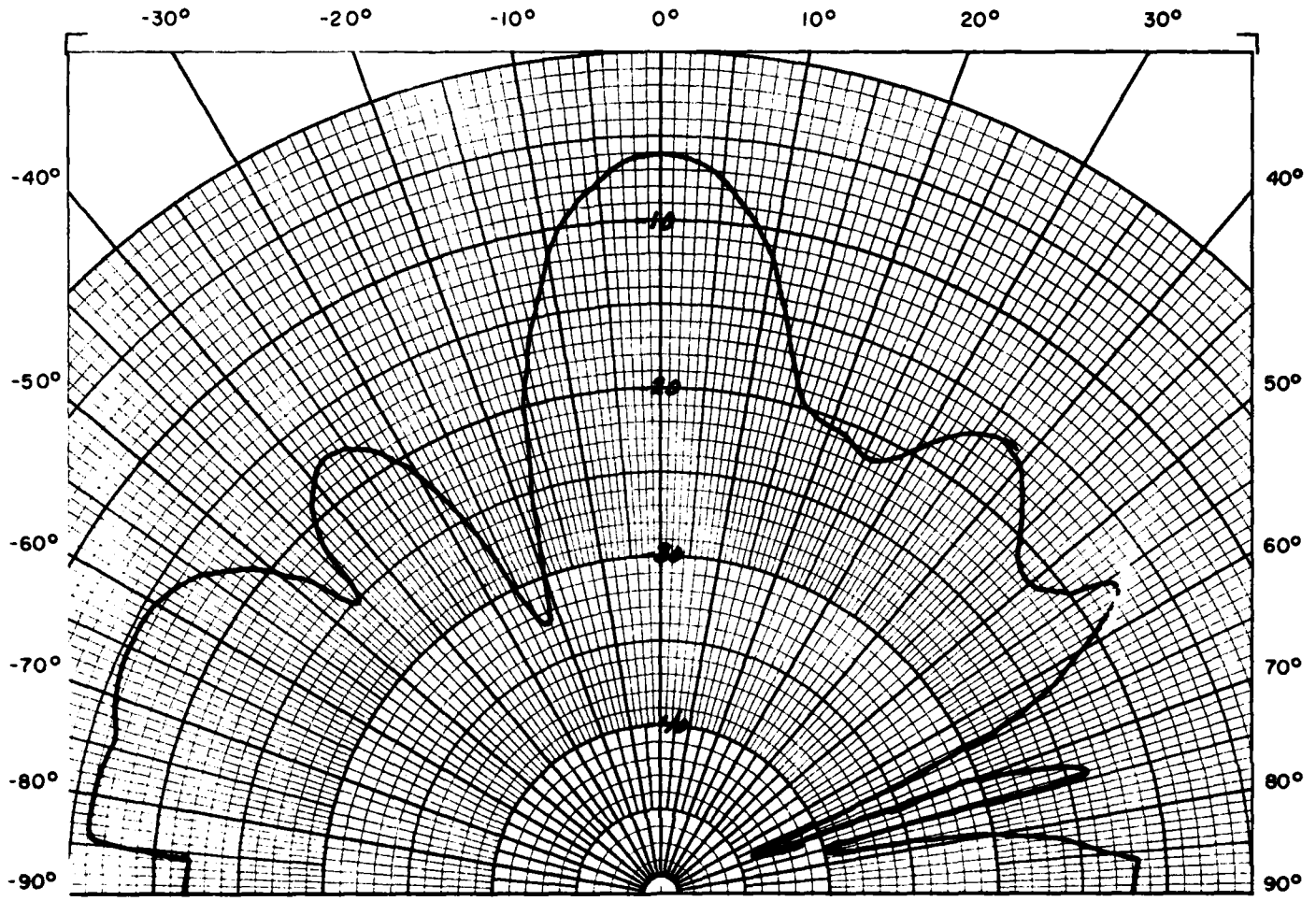


B9

TRACOR, INC. DWG. \742-111
AUSTIN, TEXAS 3/23/64 CTK/CB



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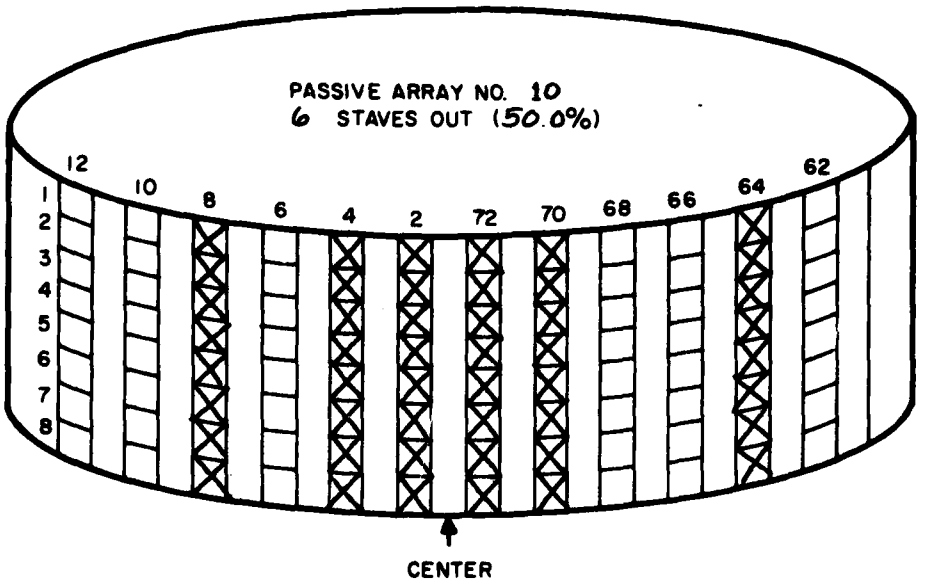
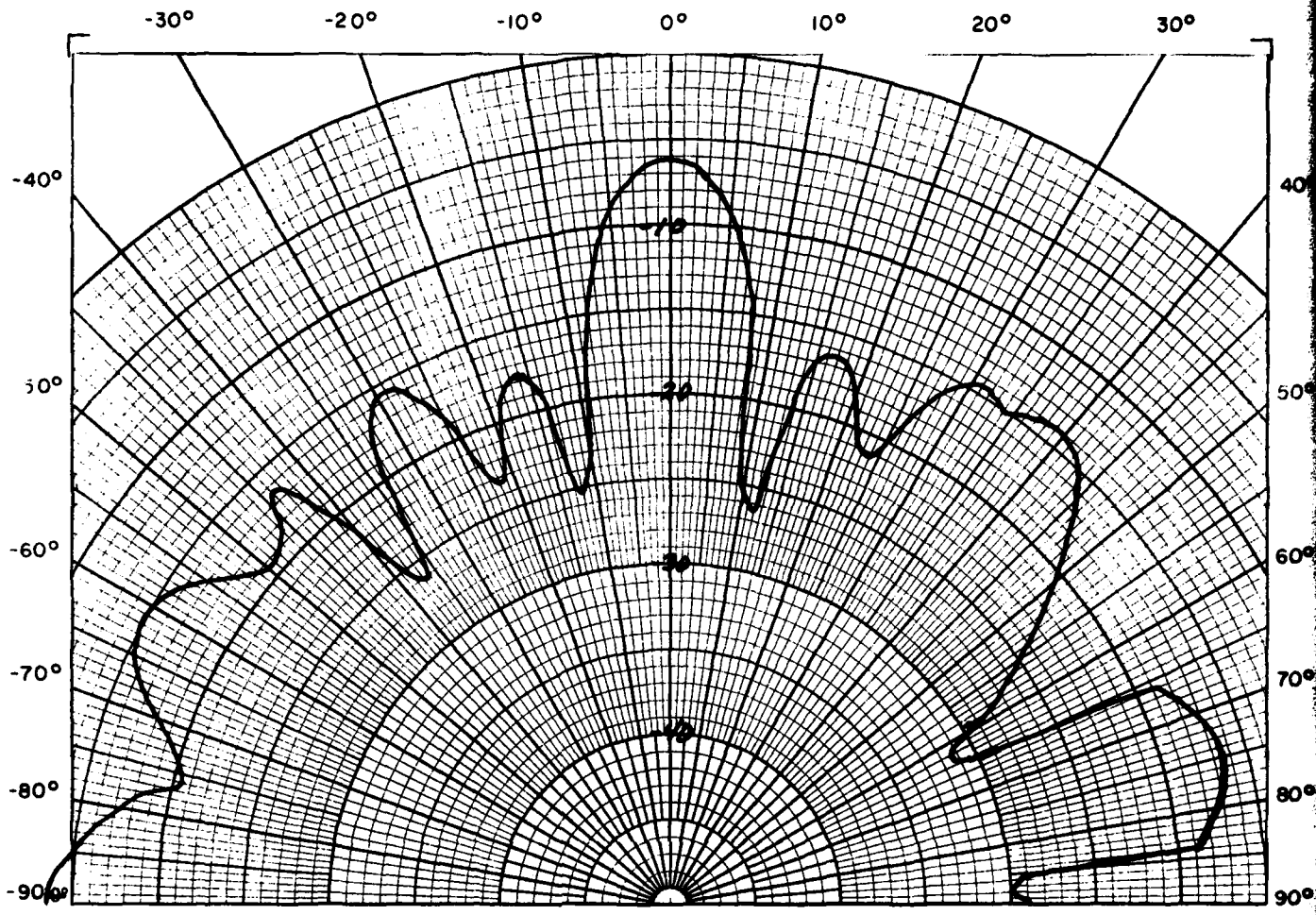


B10

TRACOR, INC. DWG. A742-111
AUSTIN, TEXAS 3/23/64 GTK/CB



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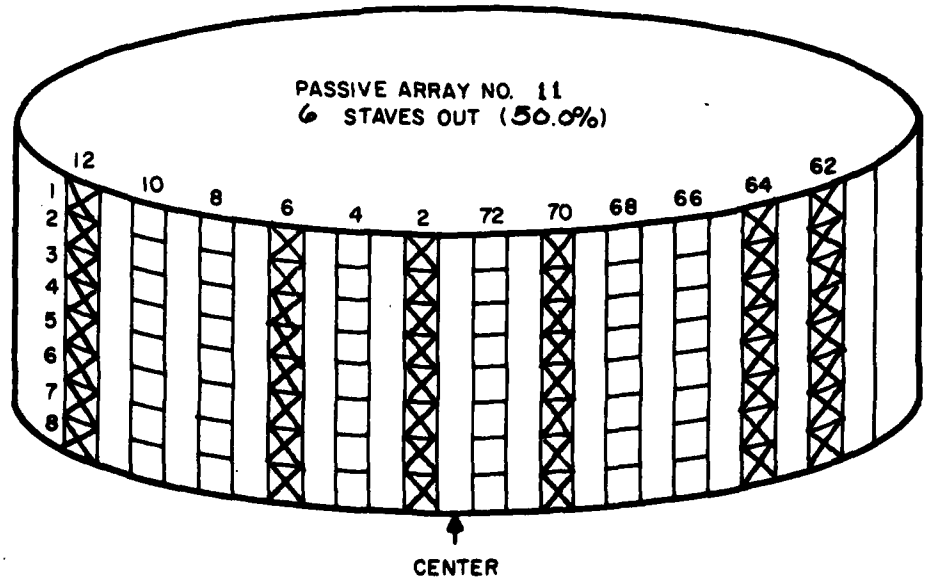
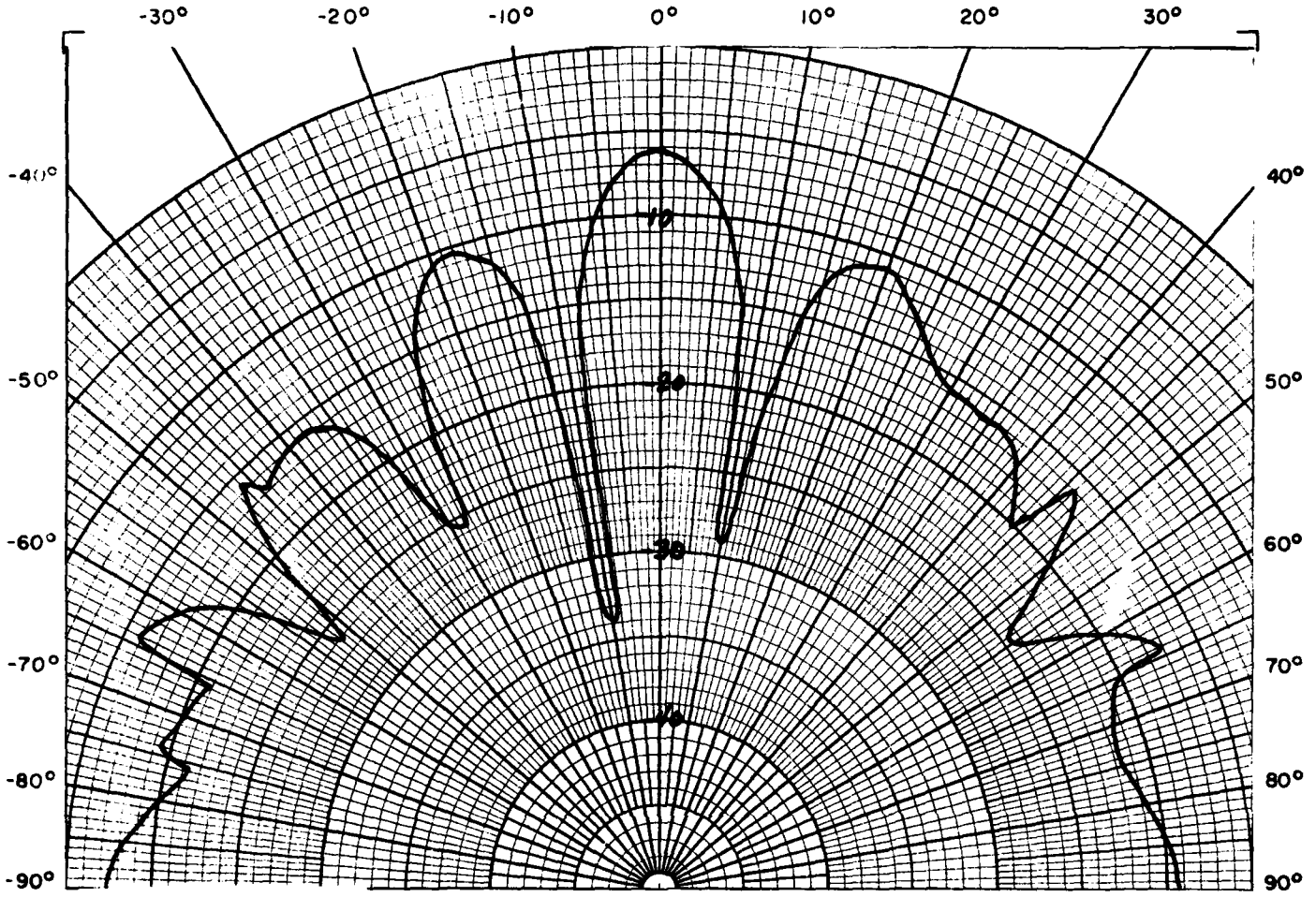


B11

TRACOR, INC. DWG. A742-111
AUSTIN, TEXAS 3/23/64 GTK/CB



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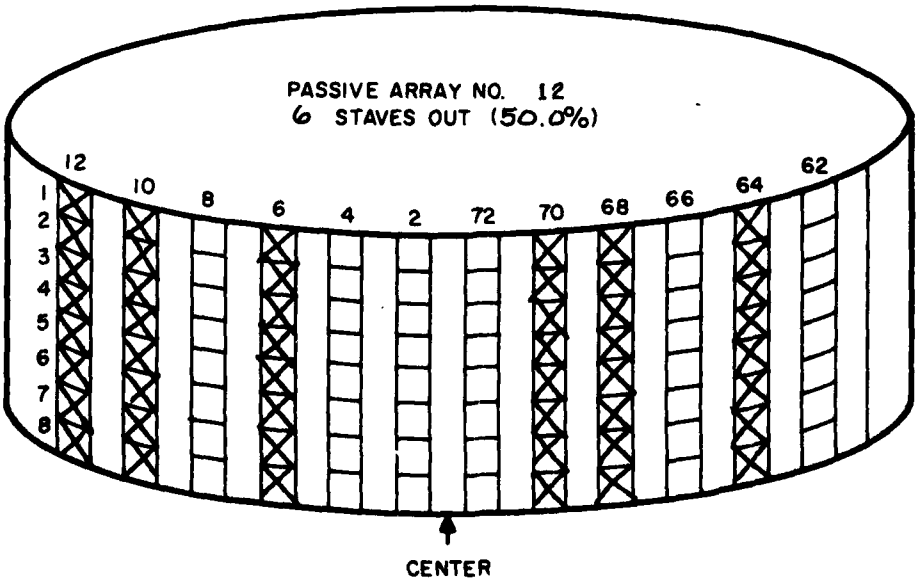
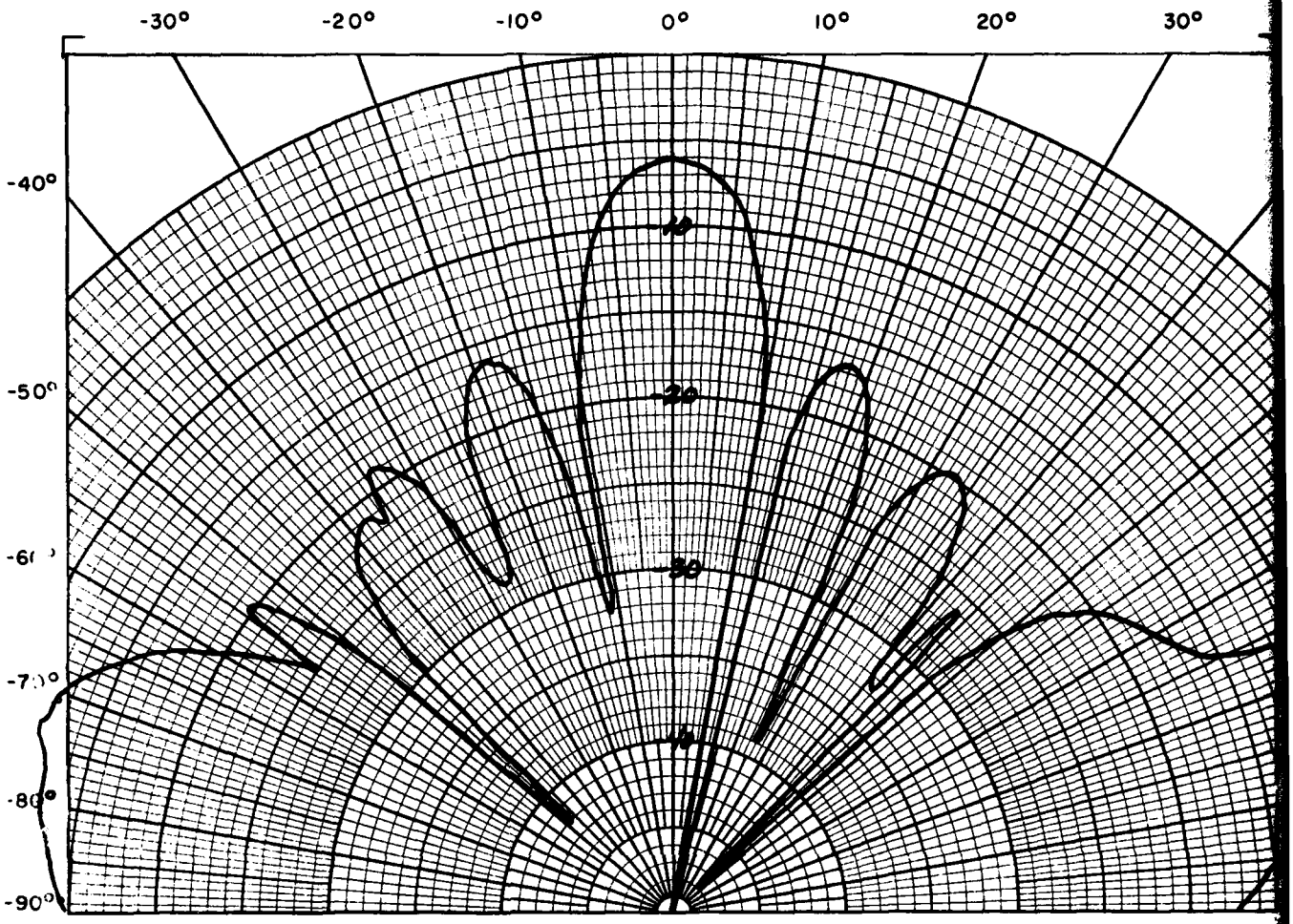


B12

TRACOR, INC. AUSTIN, TEXAS DWG. A742-111 3/23/64 GTK/CB



PASSIVE
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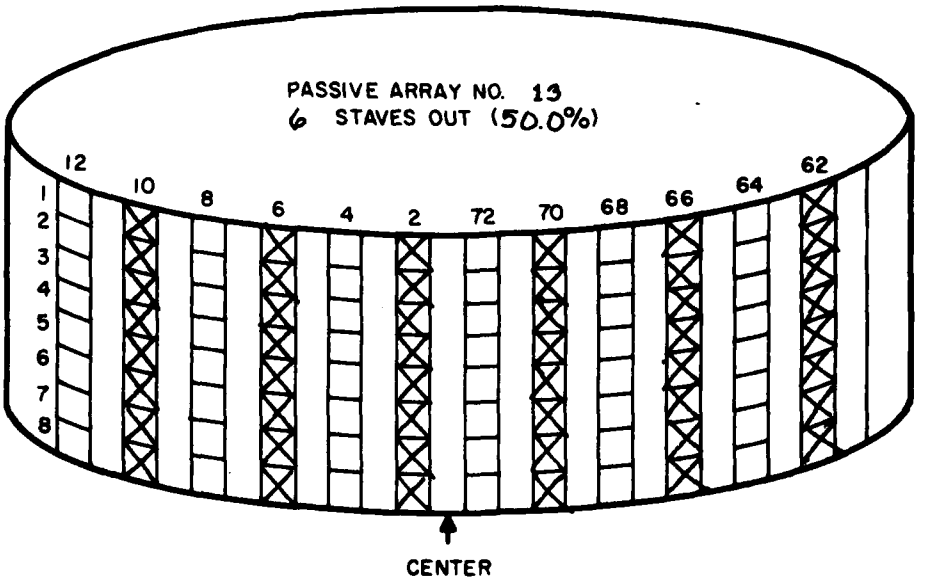
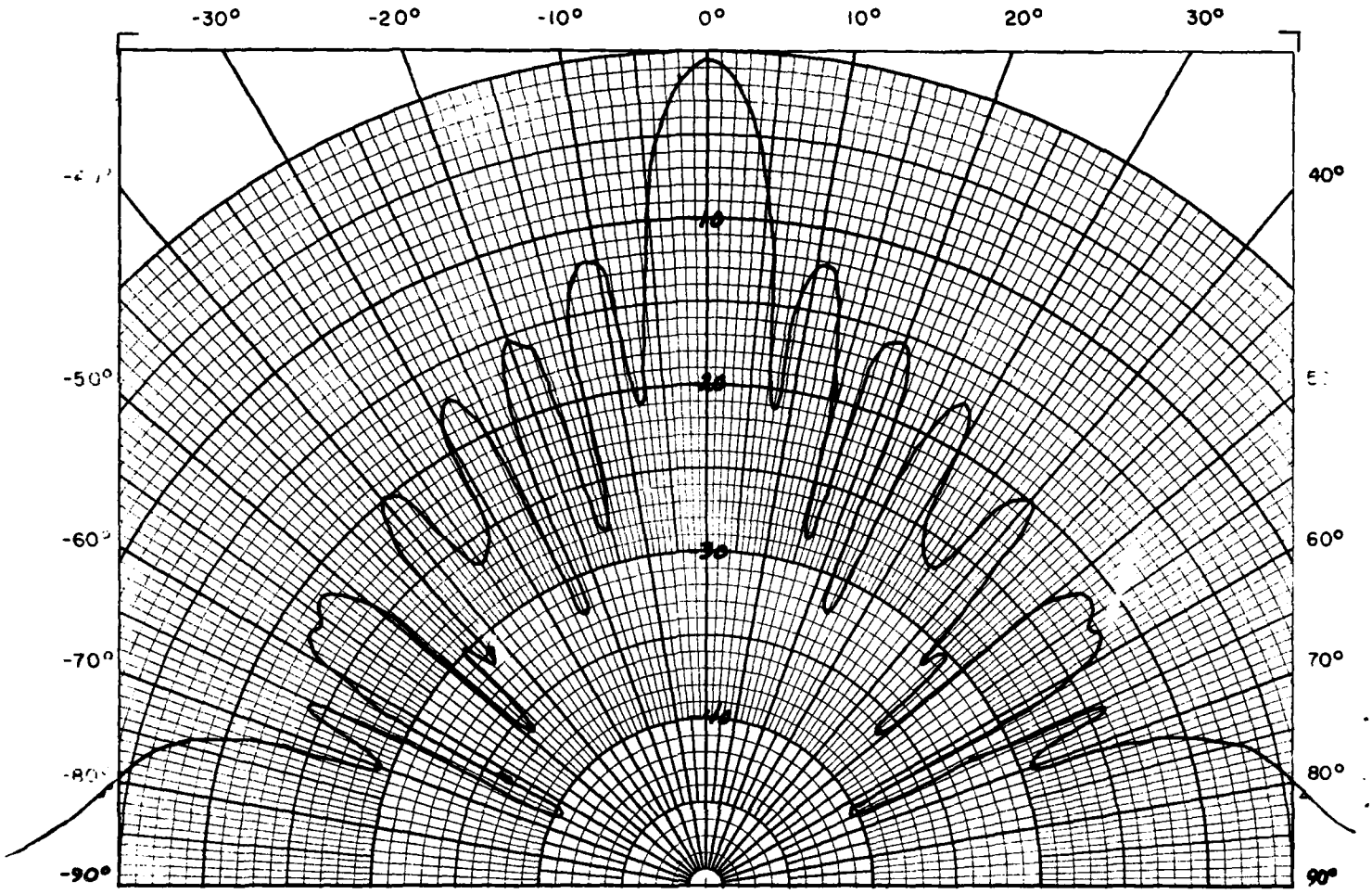


B13

TRACOR, INC. DWG. A742-II
AUSTIN, TEXAS 3/23/64 GTK/CB



PASSIVE
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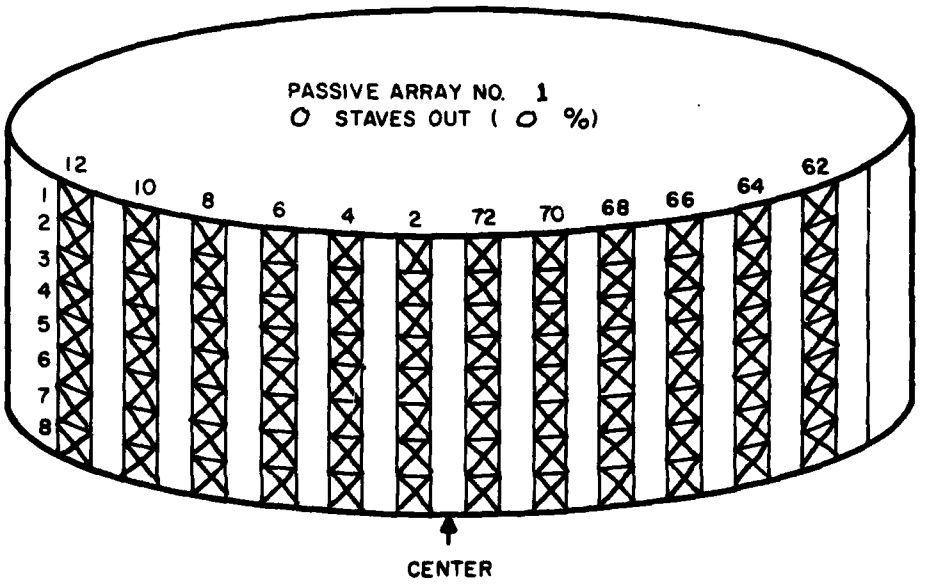
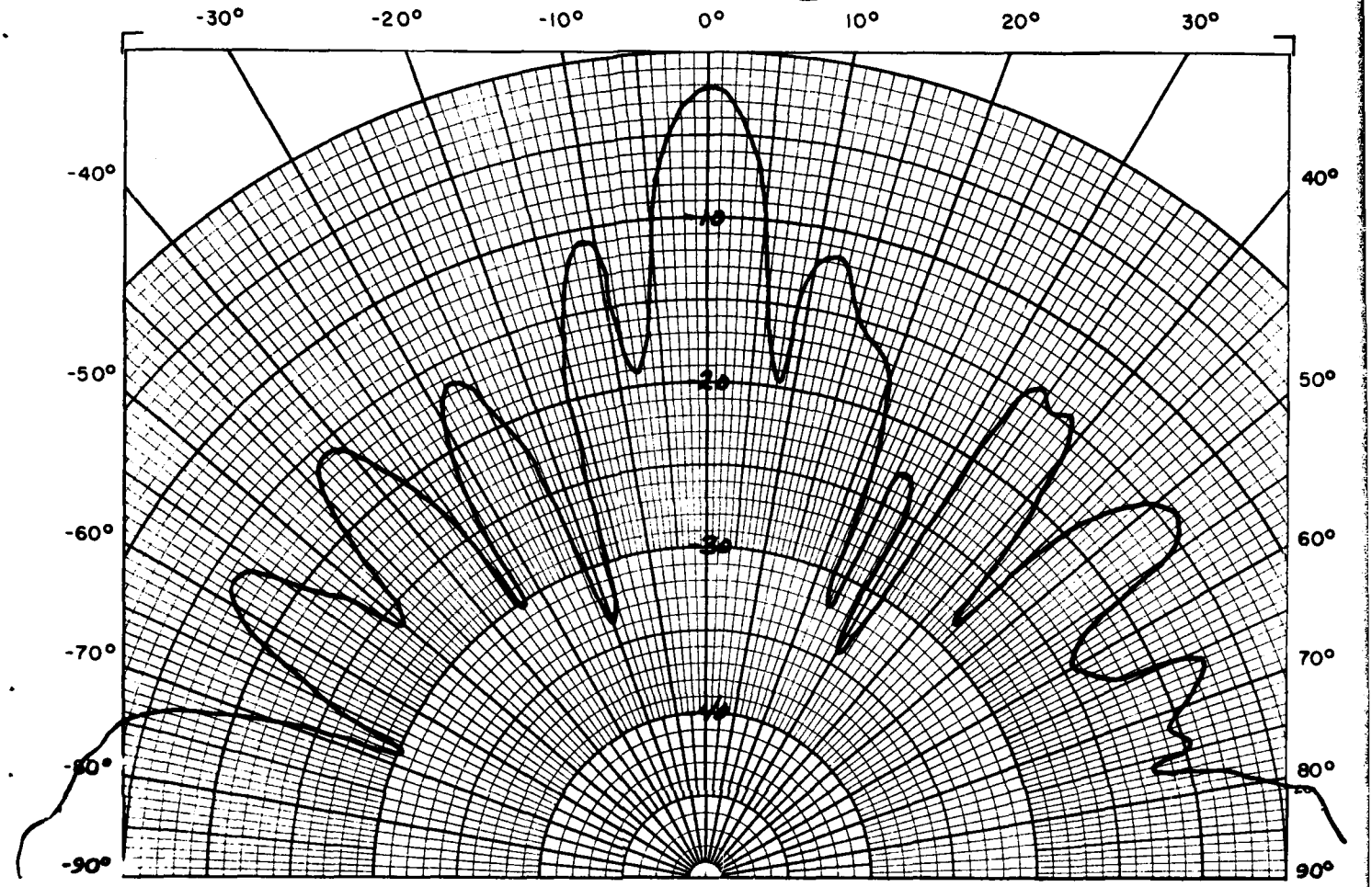


TRACOR, INC. DWG. A742-111
AUSTIN, TEXAS 3/23/64 GTK/CB



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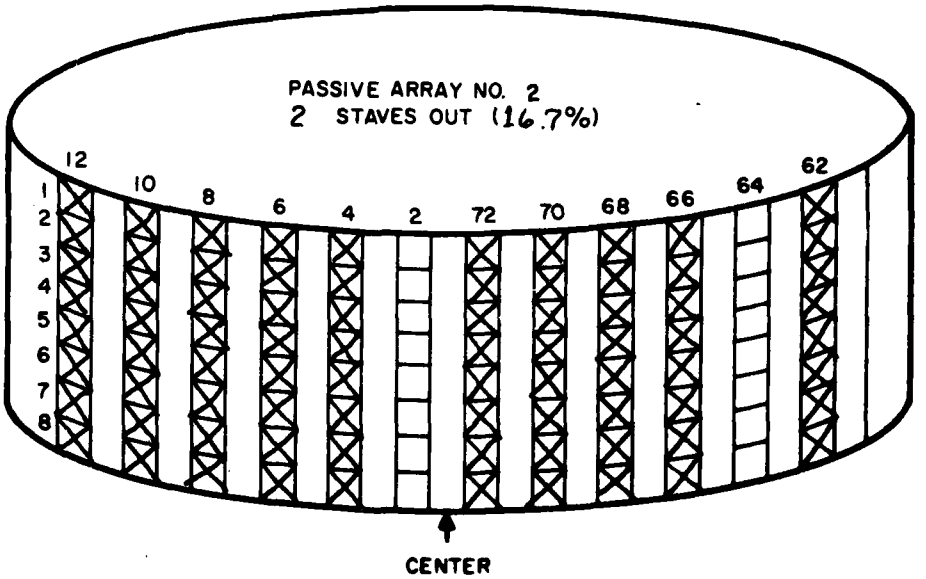
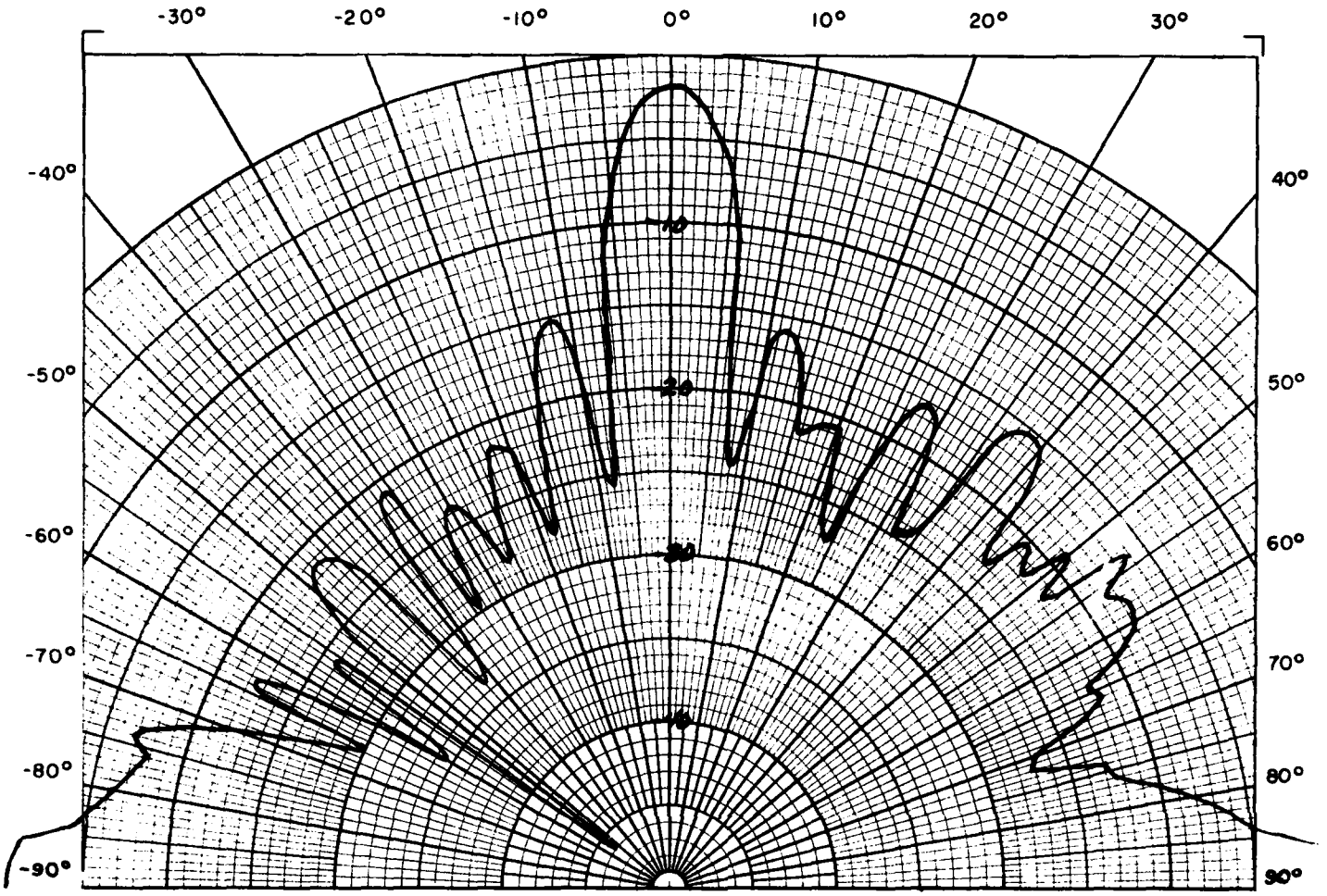


B15

TRACOR, INC. DWG. A742-111
AUSTIN, TEXAS 3/23/64 GTK/CB



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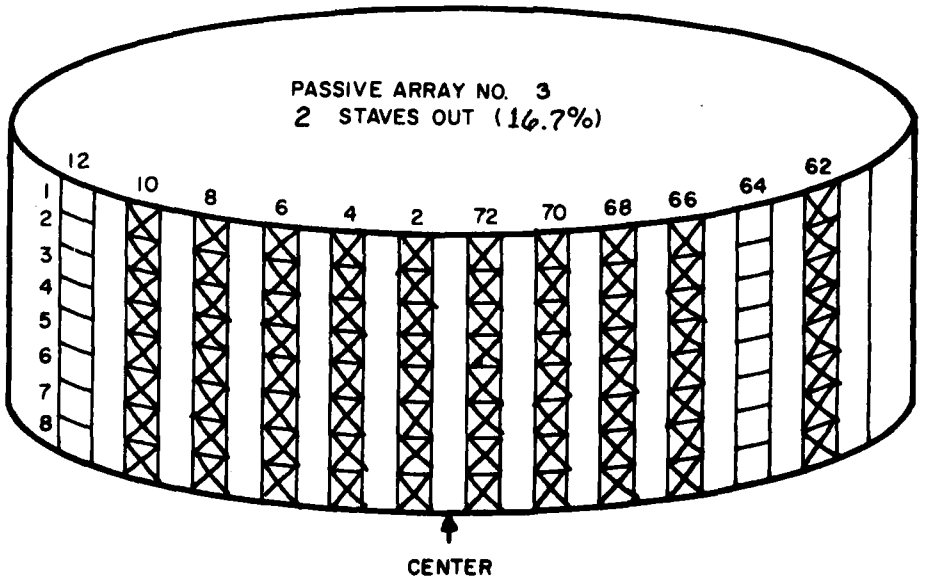
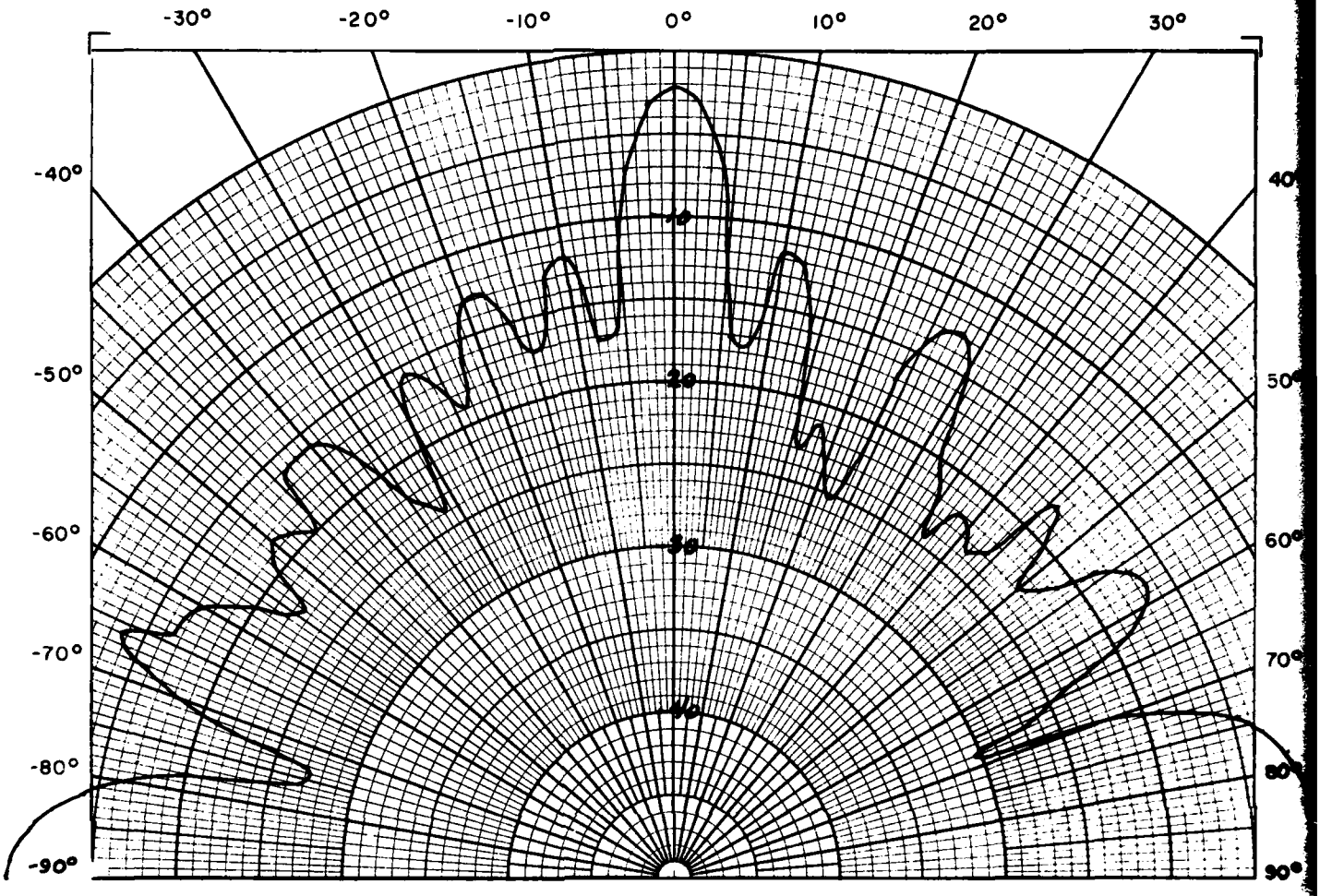


B16

TRACOR, INC. DWG. A742-111
AUSTIN, TEXAS 3/23/64 GTK/CB



PASSIVE
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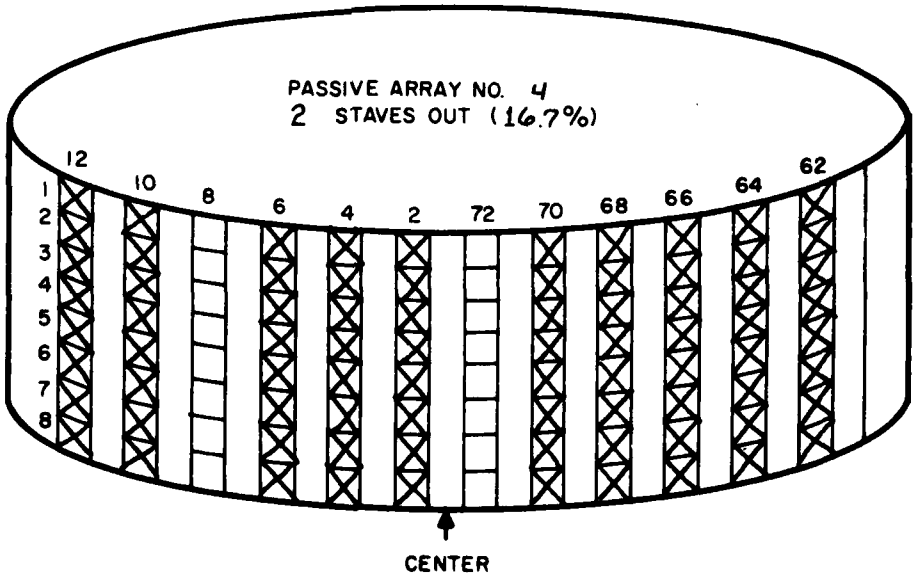
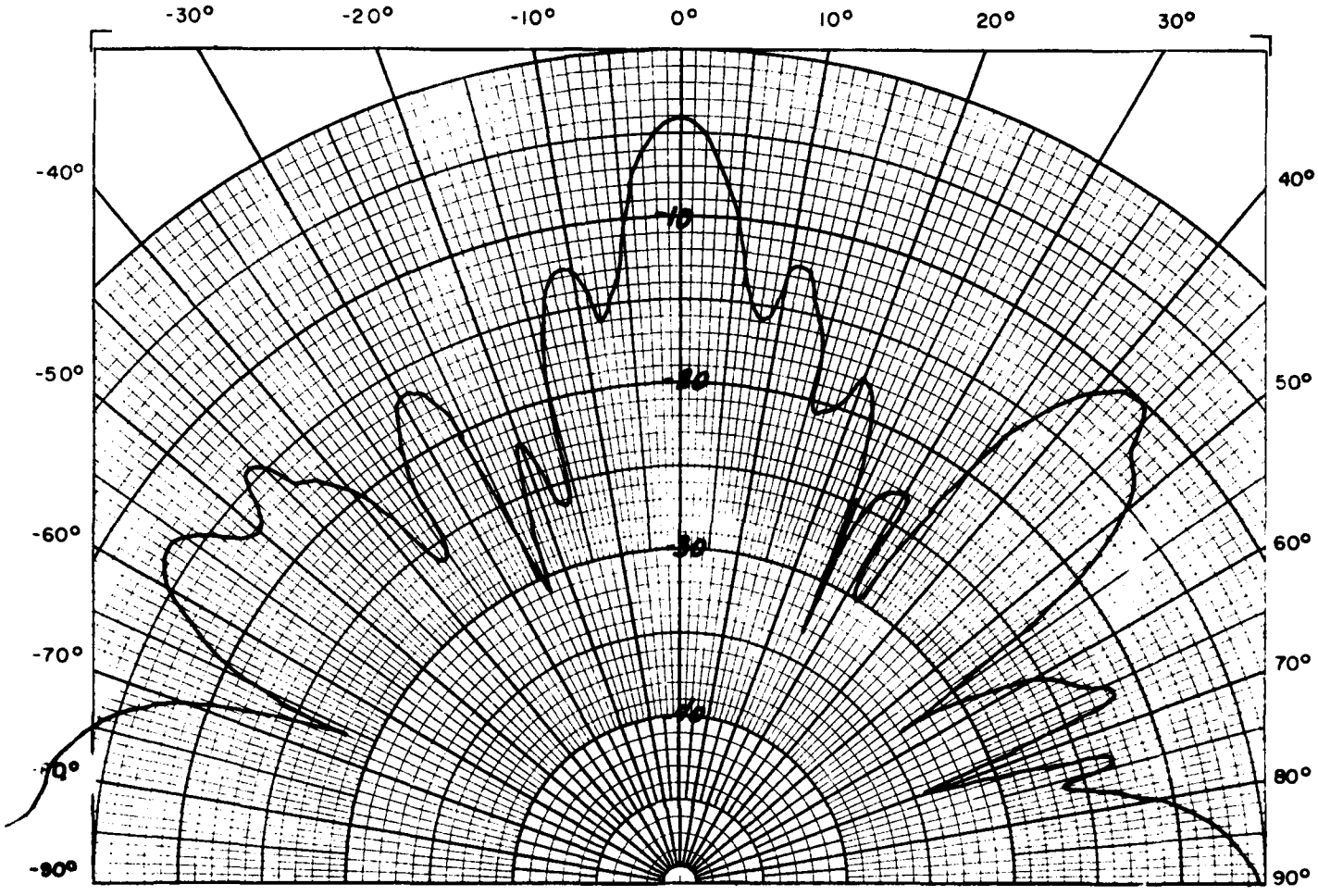


B17

TRACOR, INC. DWG. A742-111
AUSTIN, TEXAS 3/23/64 GTK/CB



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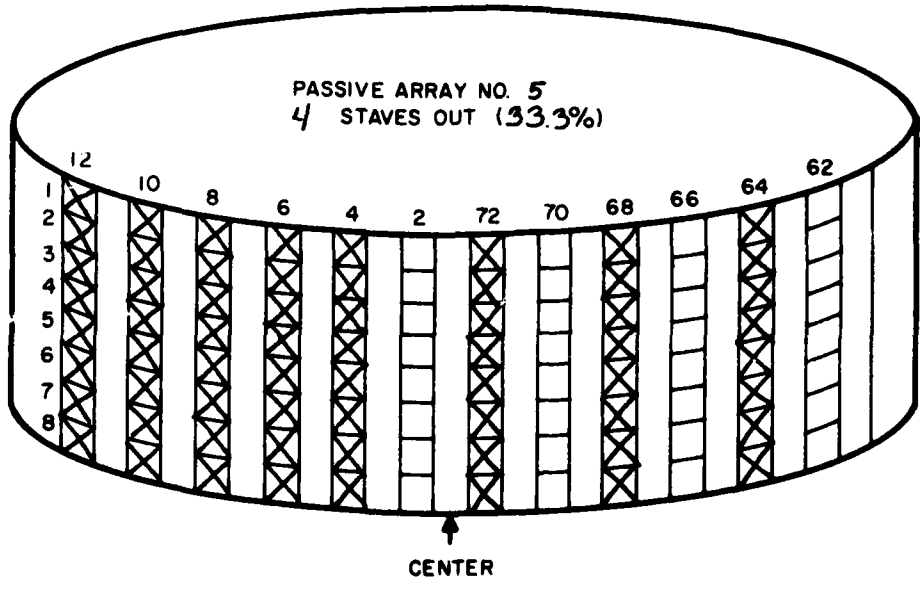
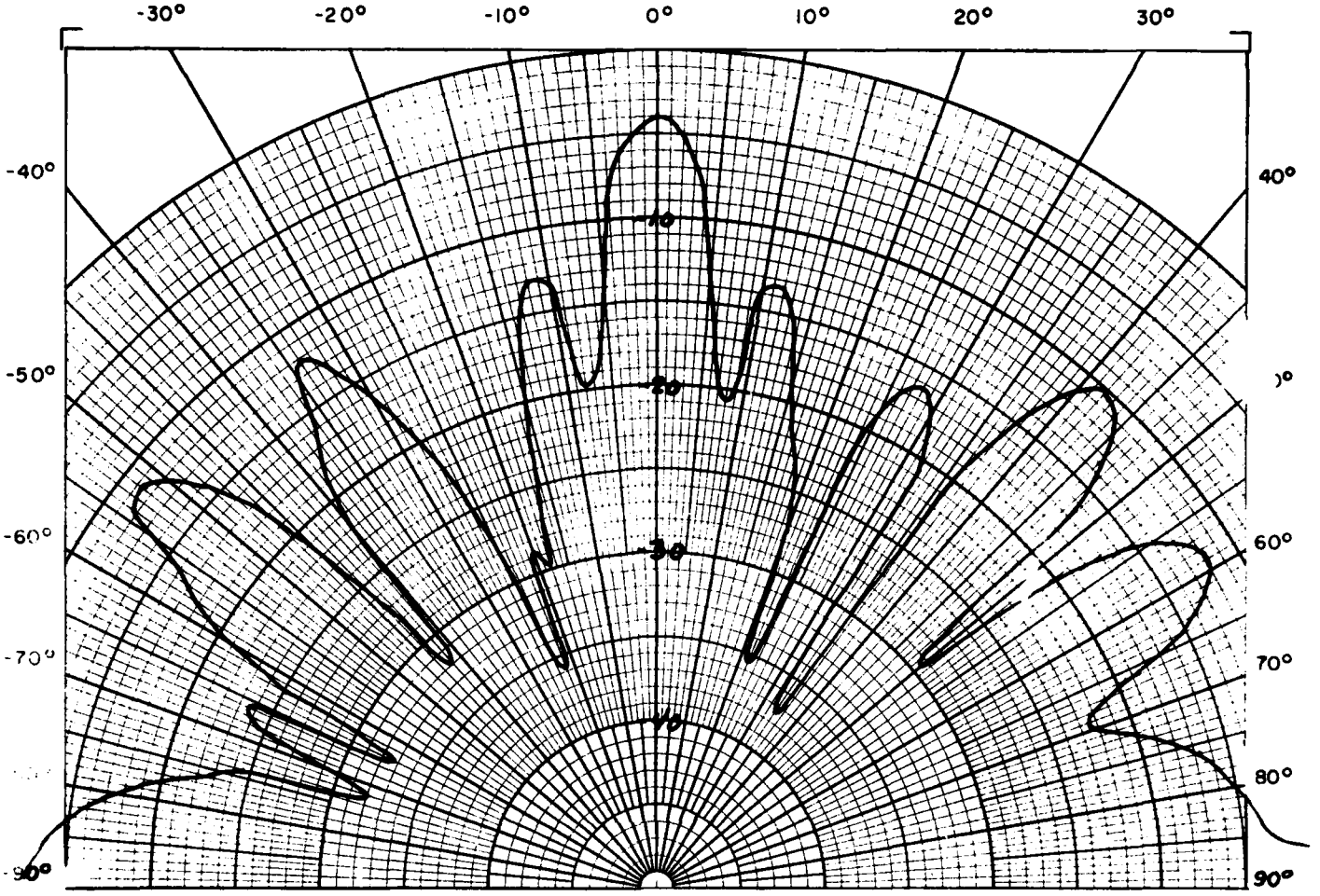


TRACOR, INC. DWG. A742-111
AUSTIN, TEXAS 3/23/64 GTK/CB



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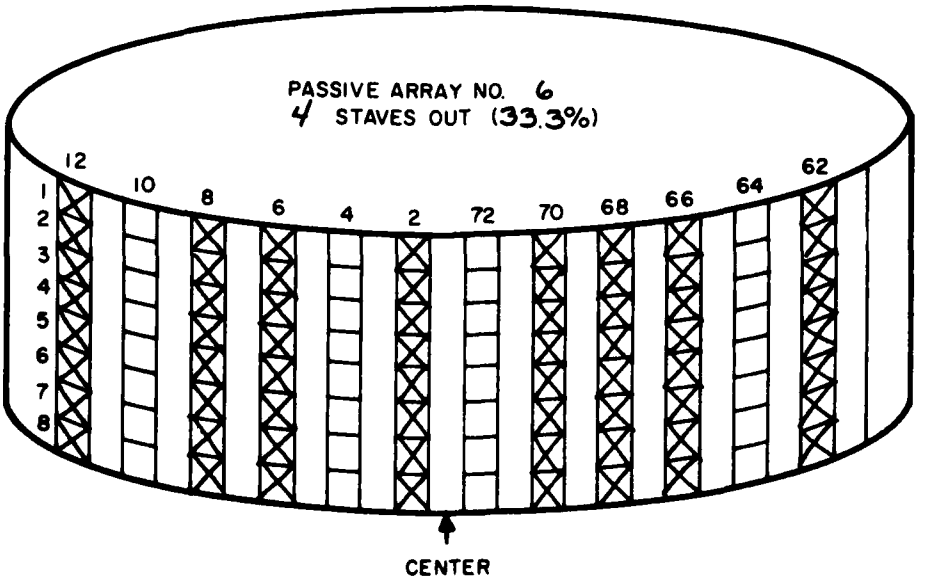
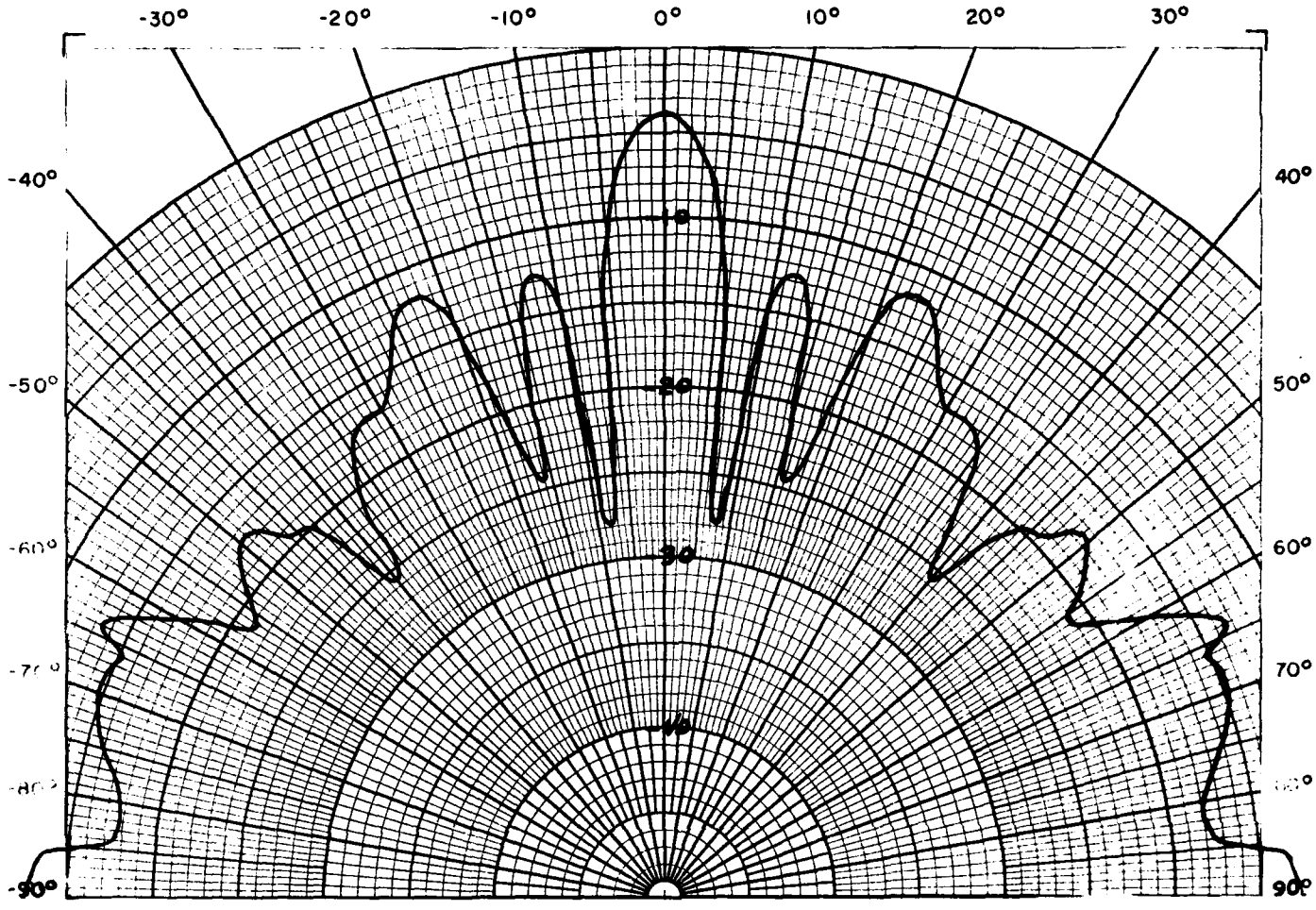


B19

TRACOR, INC. DWG. A742-111
AUSTIN, TEXAS 3/23/64 GTK/CB



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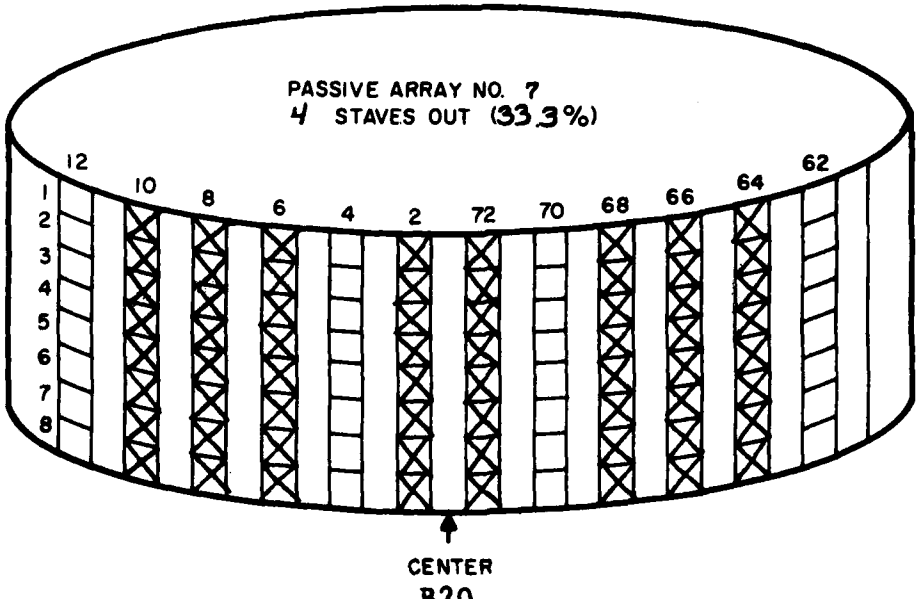
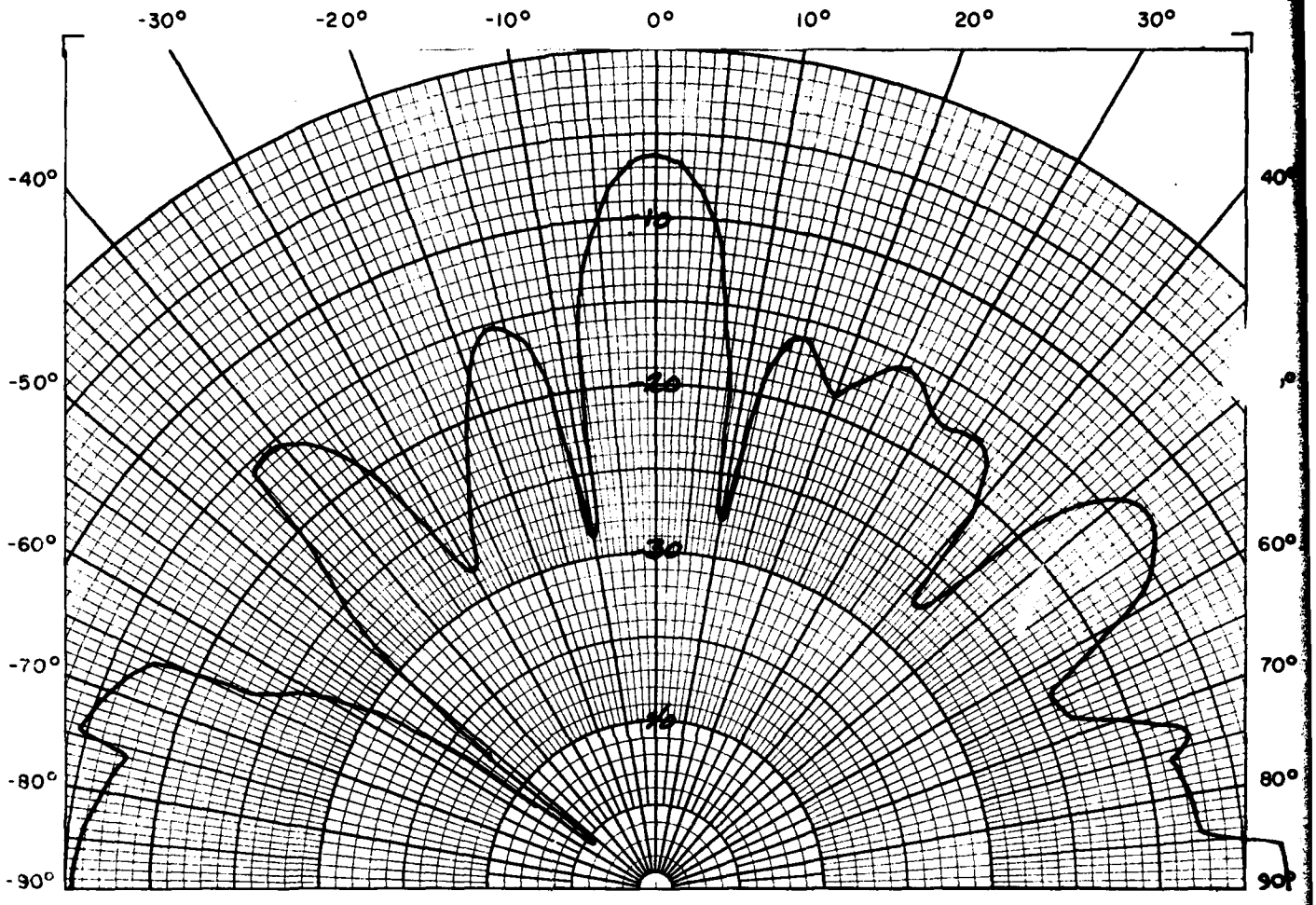


B20

TRACOR, INC. DWG. A742-111
AUSTIN, TEXAS 3/23/64 GTK/CB



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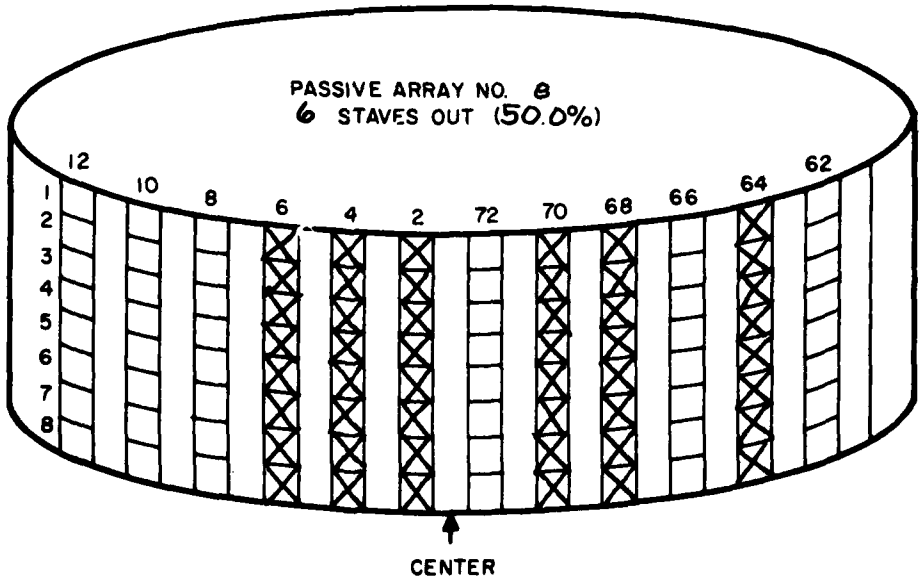
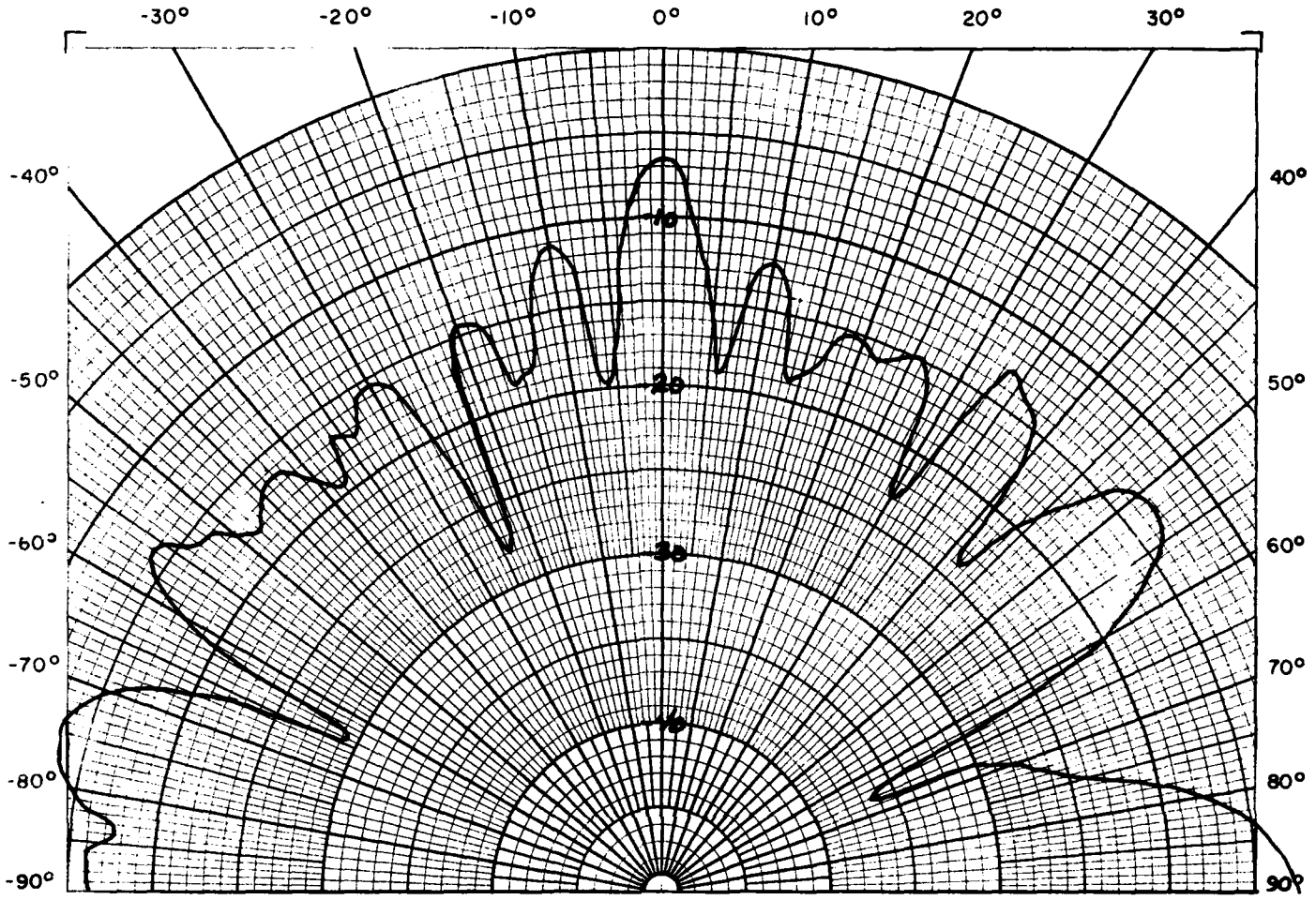


B21

TRACOR, INC. AUSTIN, TEXAS DWG. A742-111 3/23/64 BTX/CB



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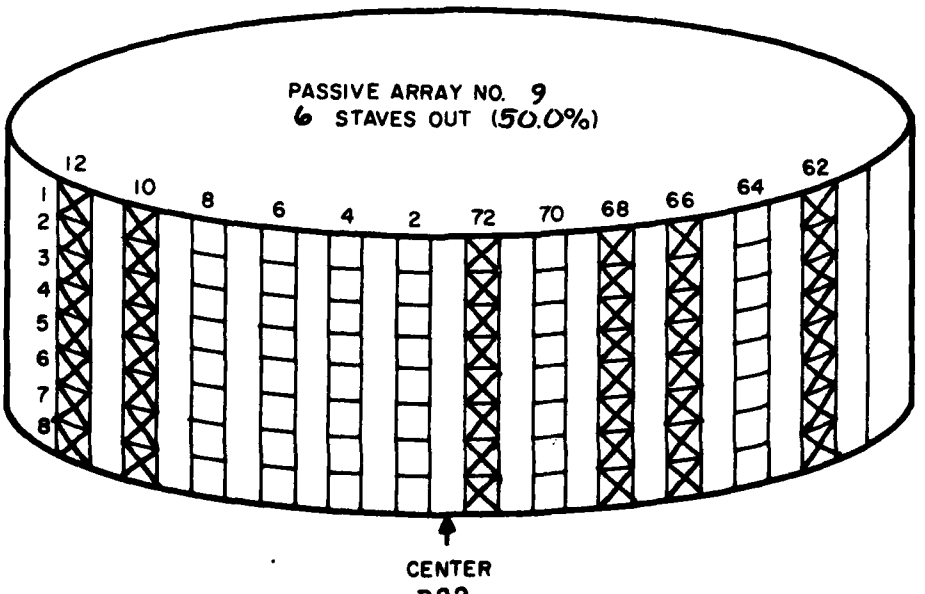
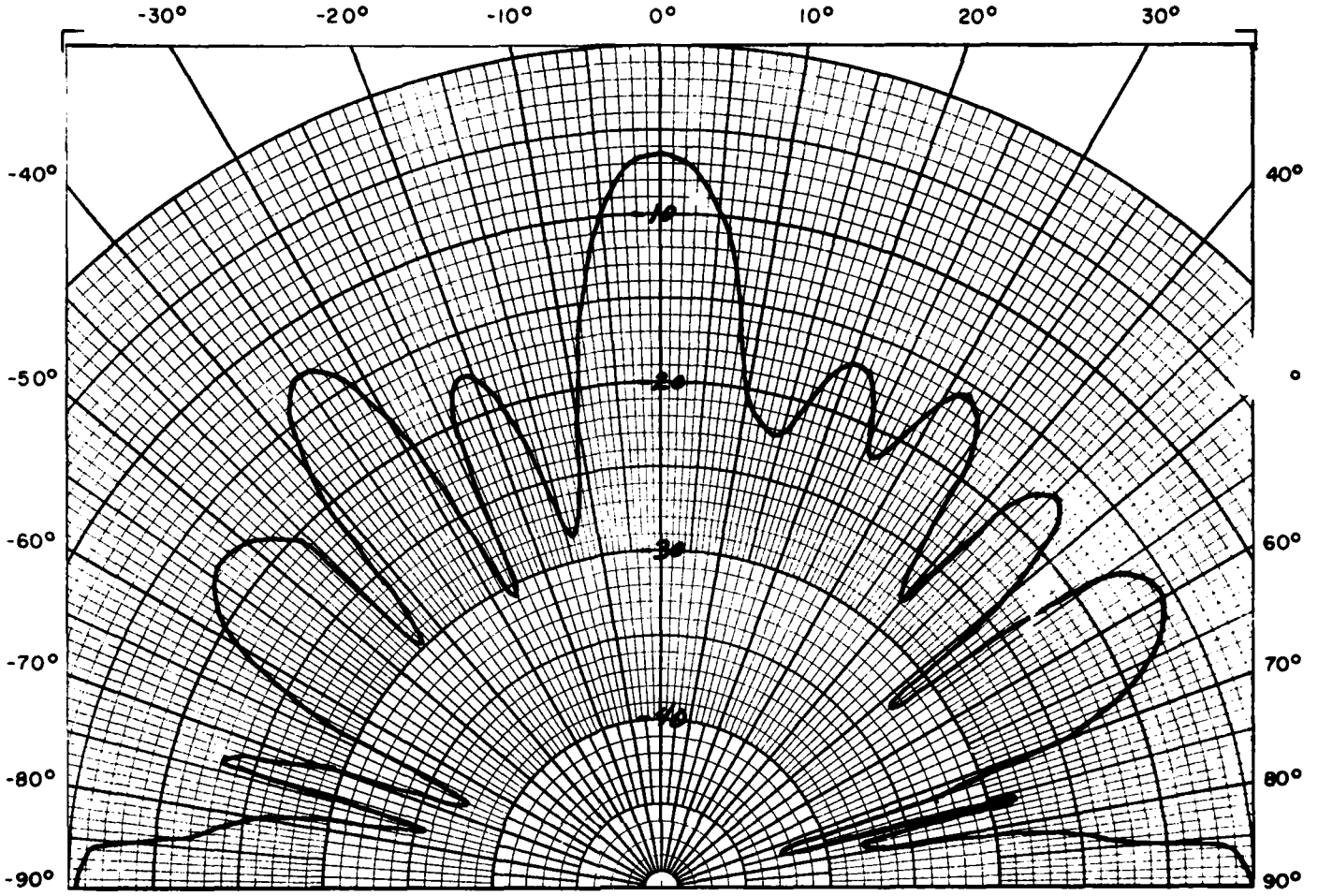


B22

TRACOR, INC DWG. A742-111
AUSTIN, TEXAS 3/23/64 GTK/CB



PASSIVE
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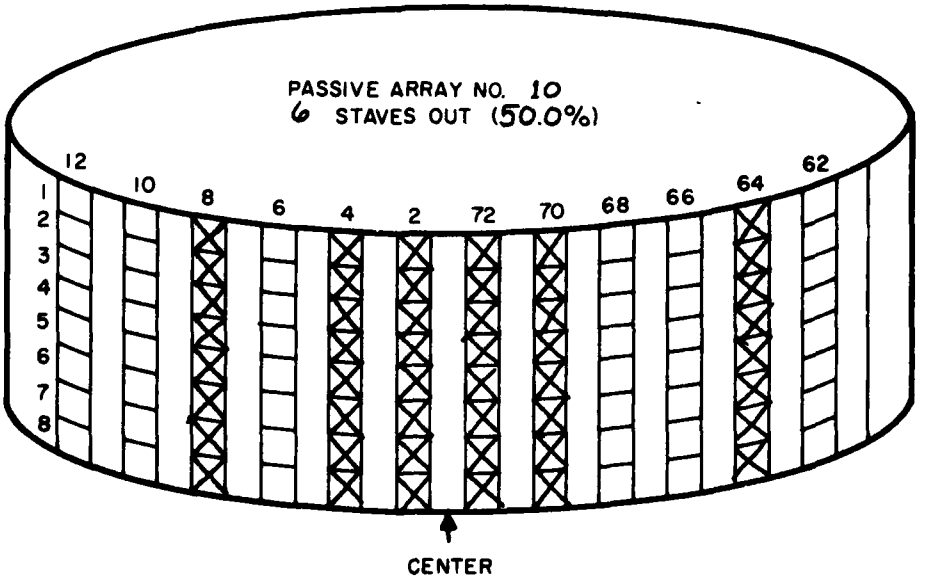
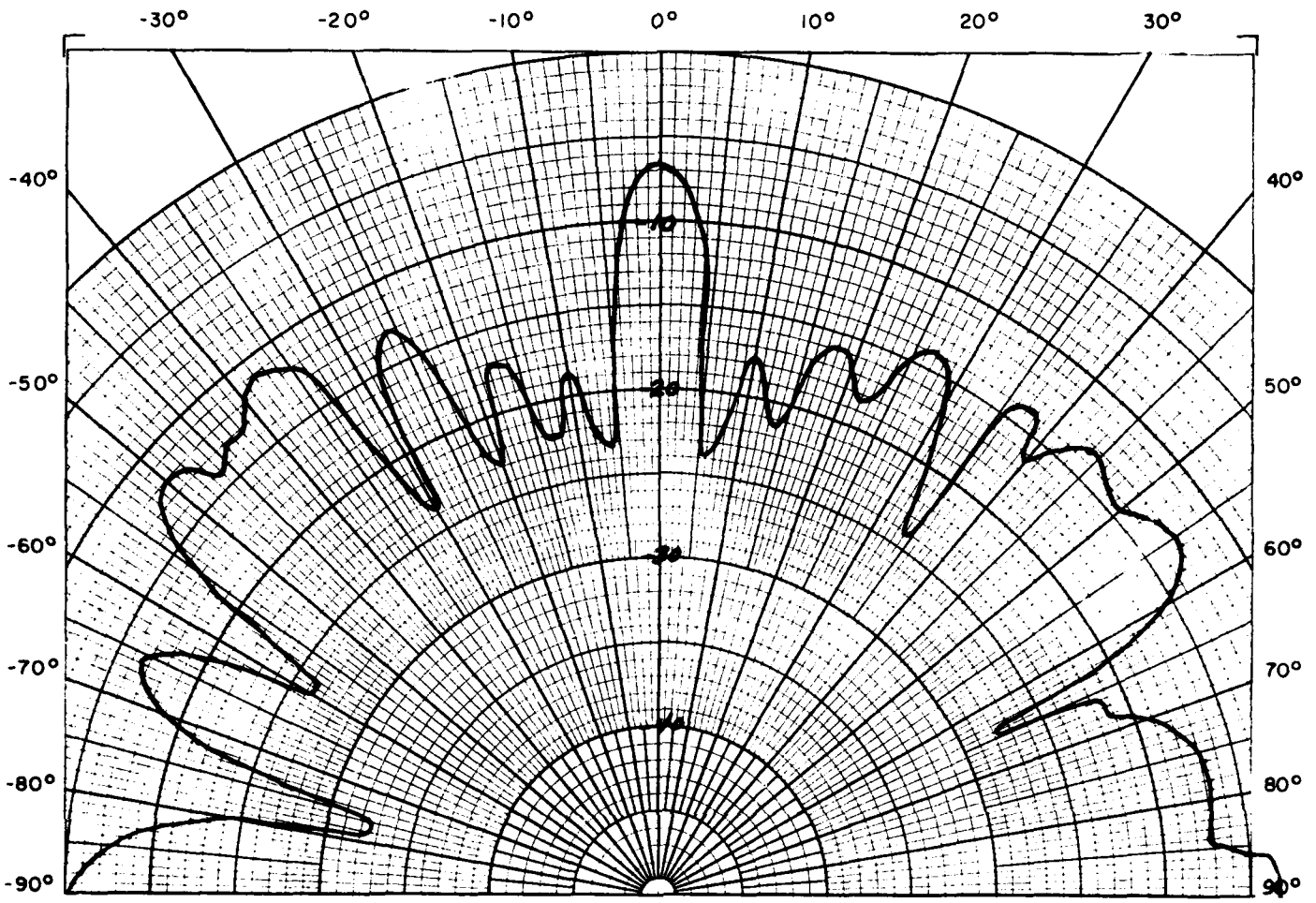


B23

TRACOR, INC. DWG. A742-111
AUSTIN, TEXAS 3/23/64 GTK/CB



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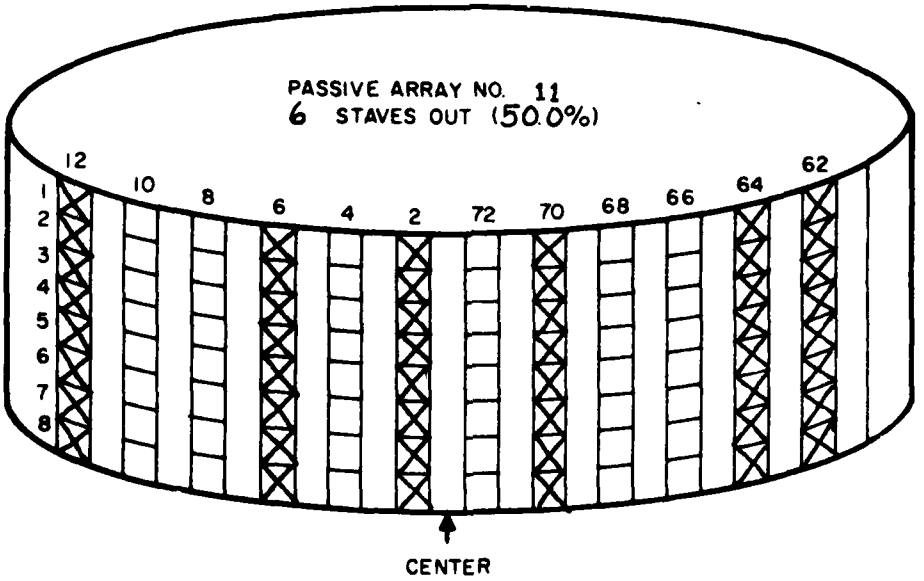
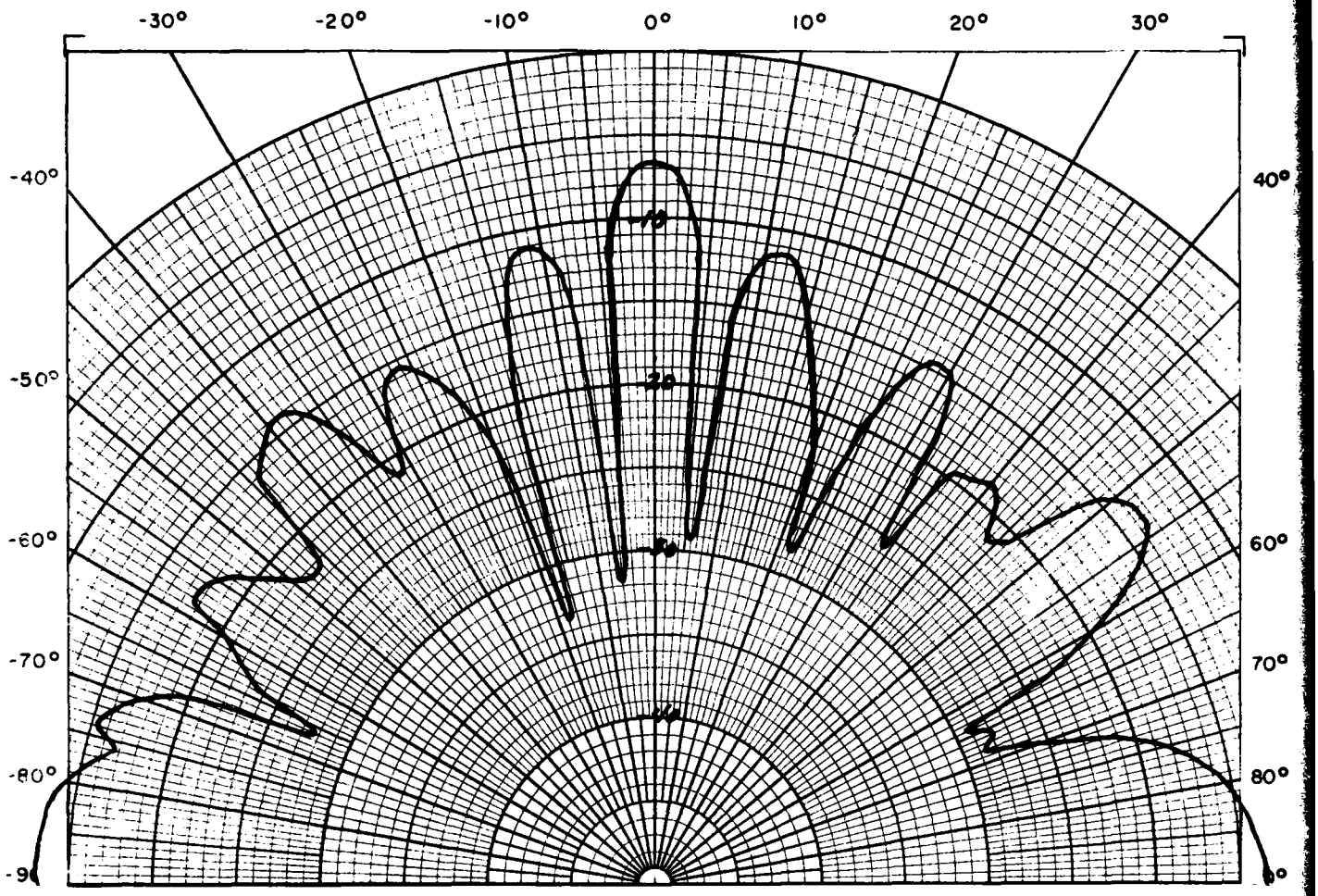


B24

TRACOR, INC. DWG. A742-111
AUSTIN, TEXAS 3/23/64 GTK/CB



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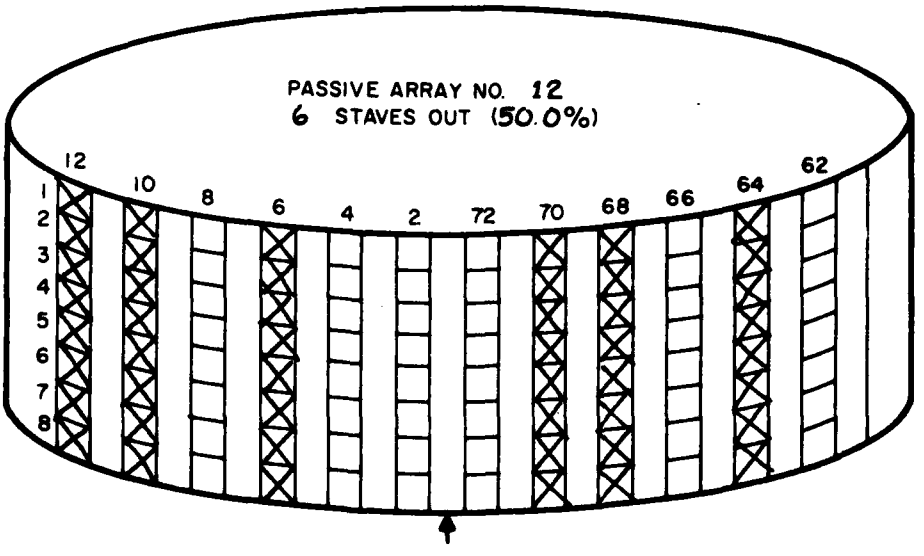
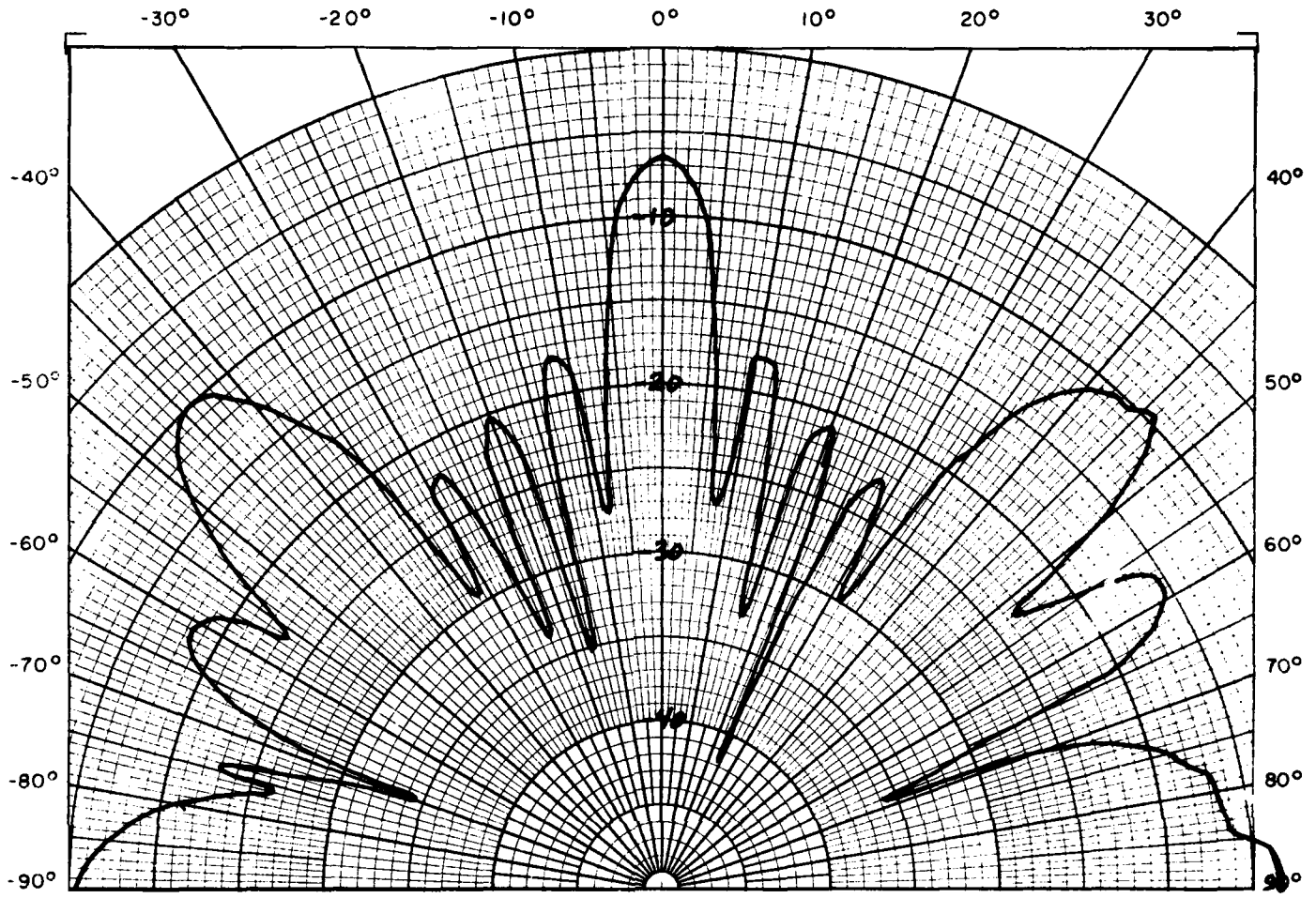
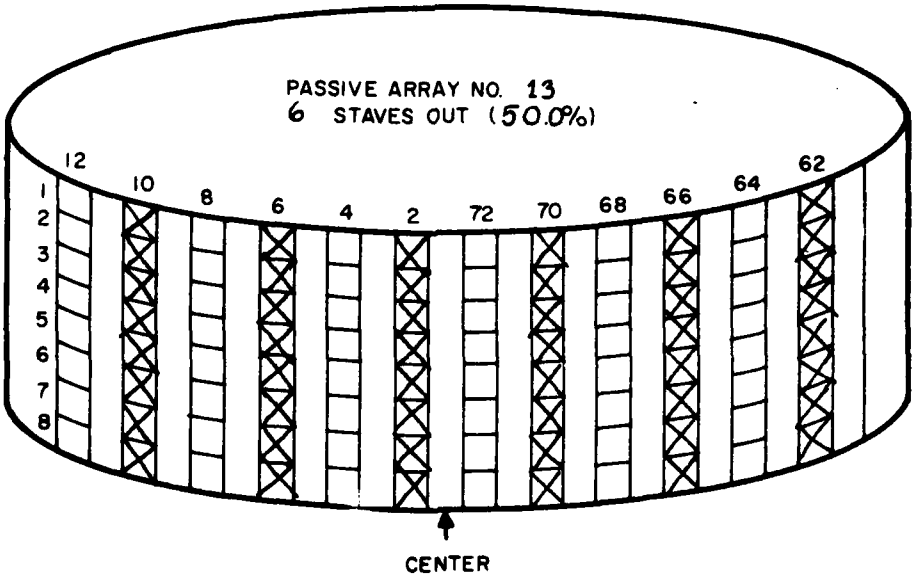


B25

TRACOR, INC. DWG. A742-111
AUSTIN, TEXAS 3/23/64 GTK/CB



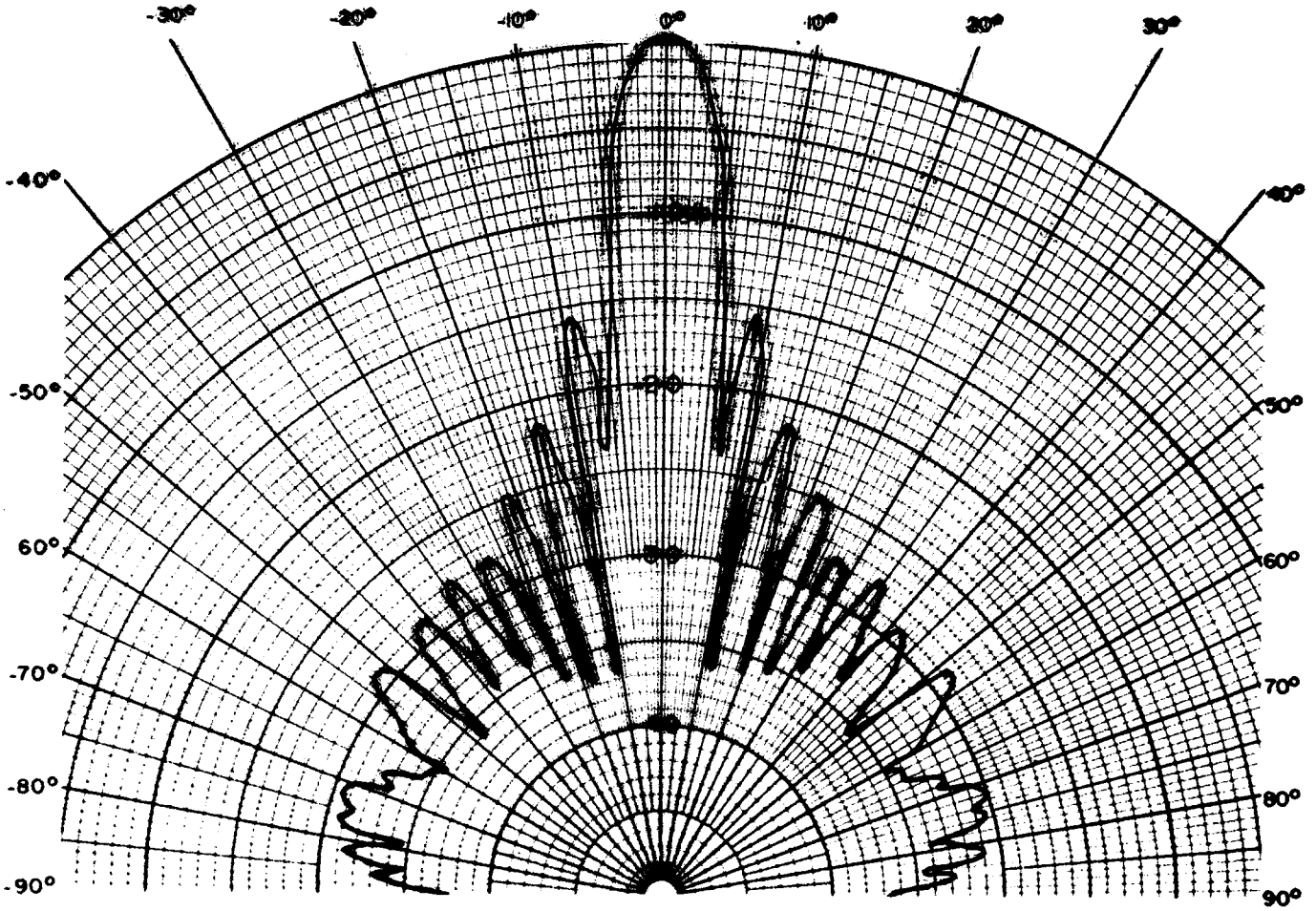
PASSIVE
f= 2.5 KC



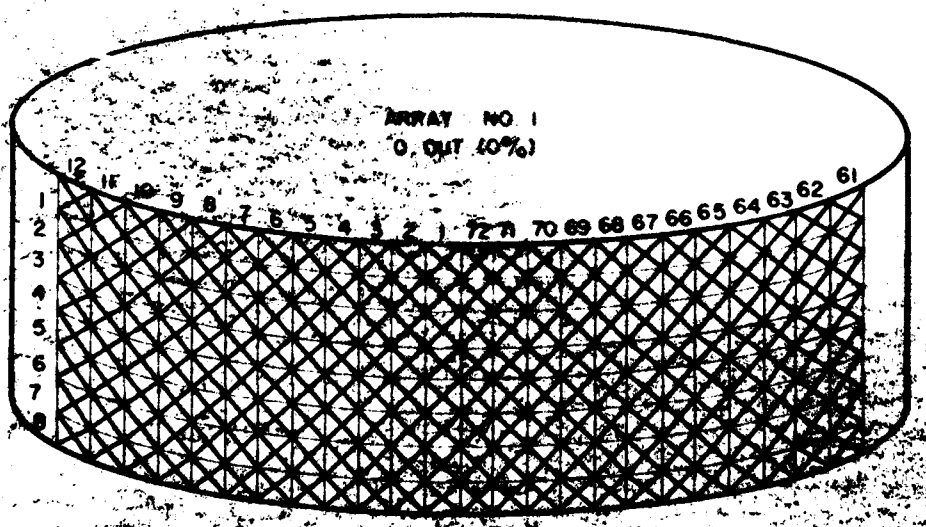
TRACOR, INC. DWG. A742-111
AUSTIN, TEXAS 3/23/64 GTK/CB

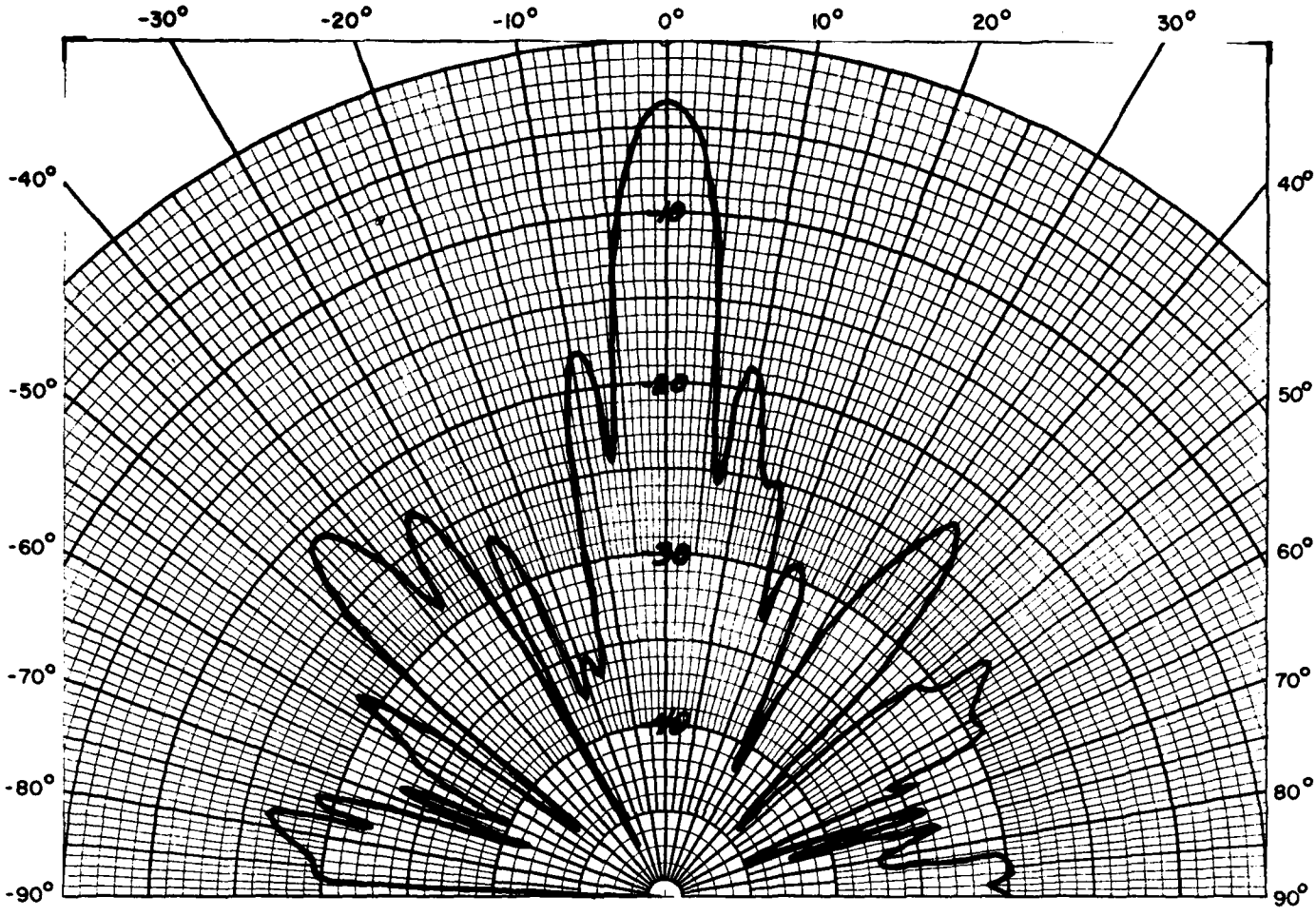
TRACOR, INC. 1701 Guadalupe St Austin 1, Texas

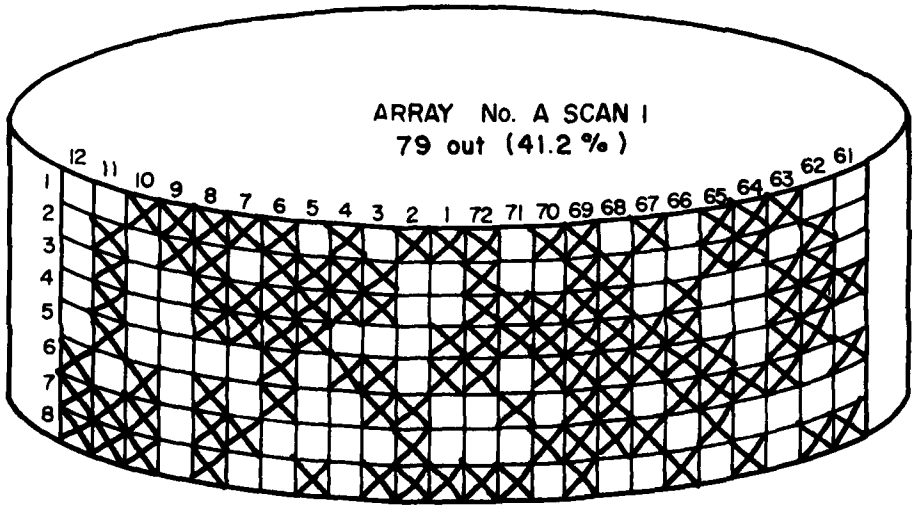
APPENDIX C
Interrelated A-Scan Beam Patterns



HORIZONTAL RECEIVE
0° TILT ANGLE; 3.5 KC
STRAIGHT-LINE PHASING
AND XN-2 SHADING.

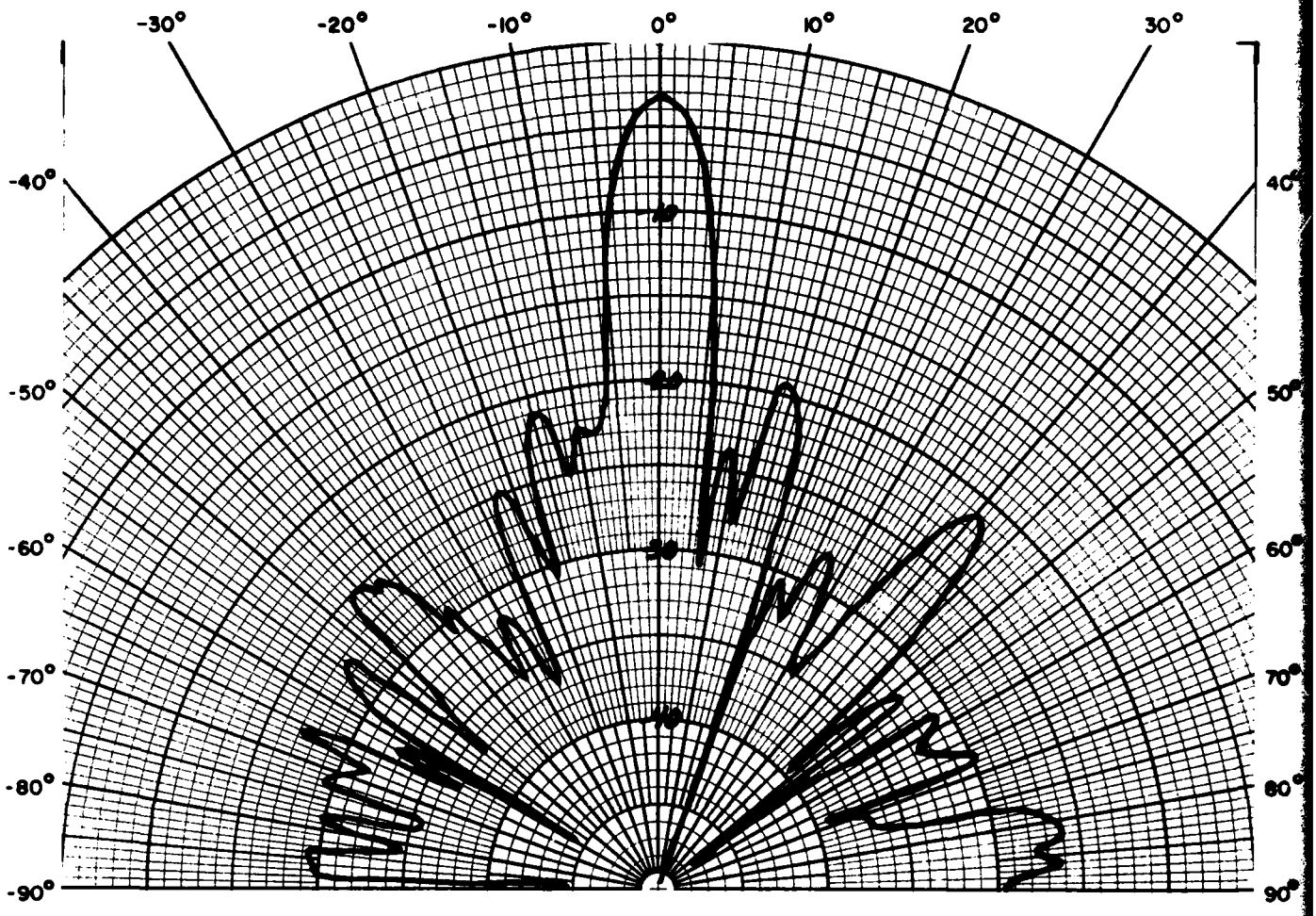


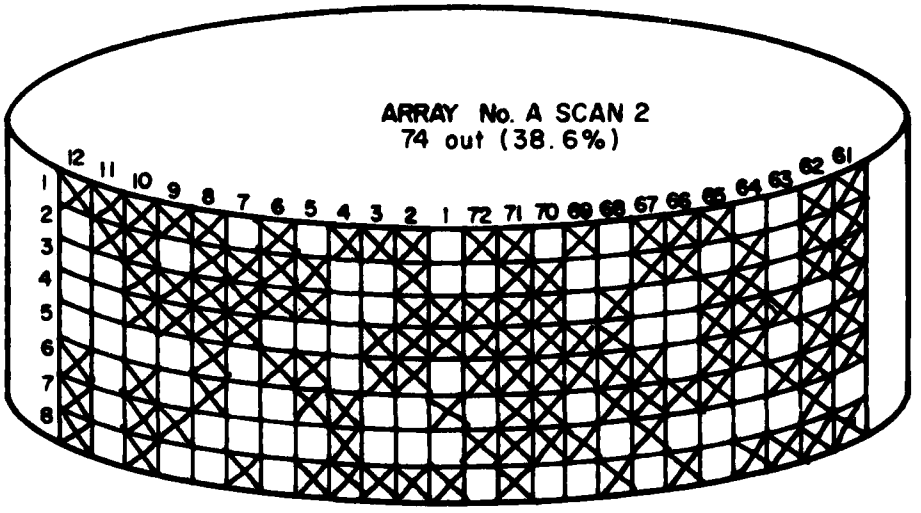




C1

TRACOR, INC. DWG A?000-
AUSTIN, TEXAS





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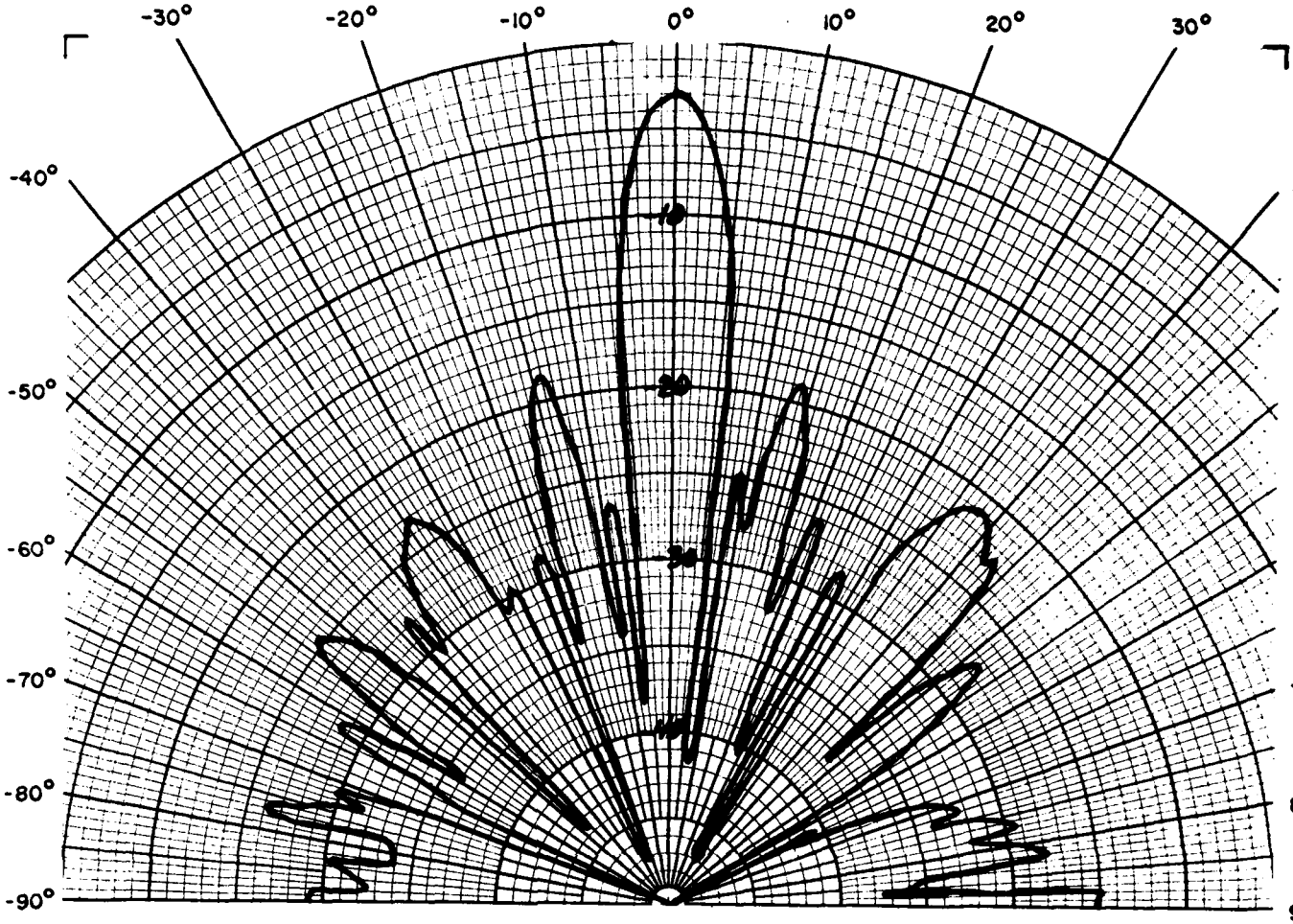
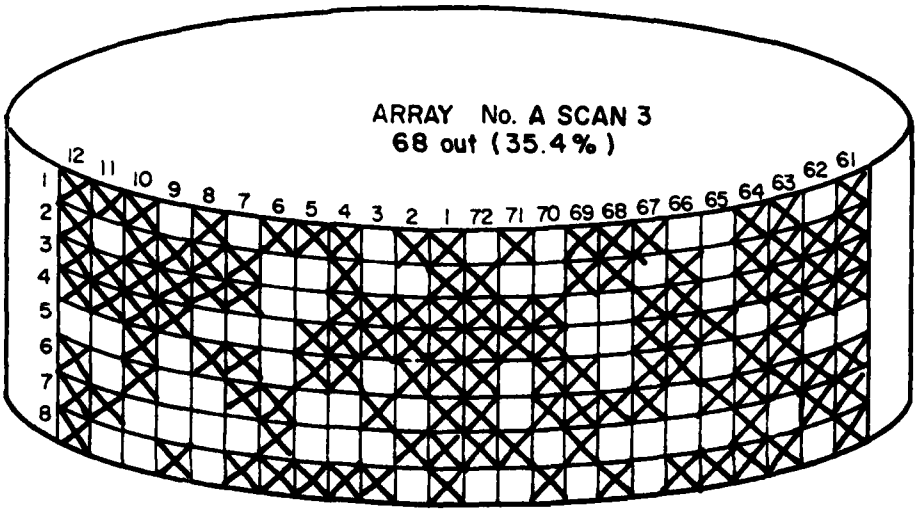
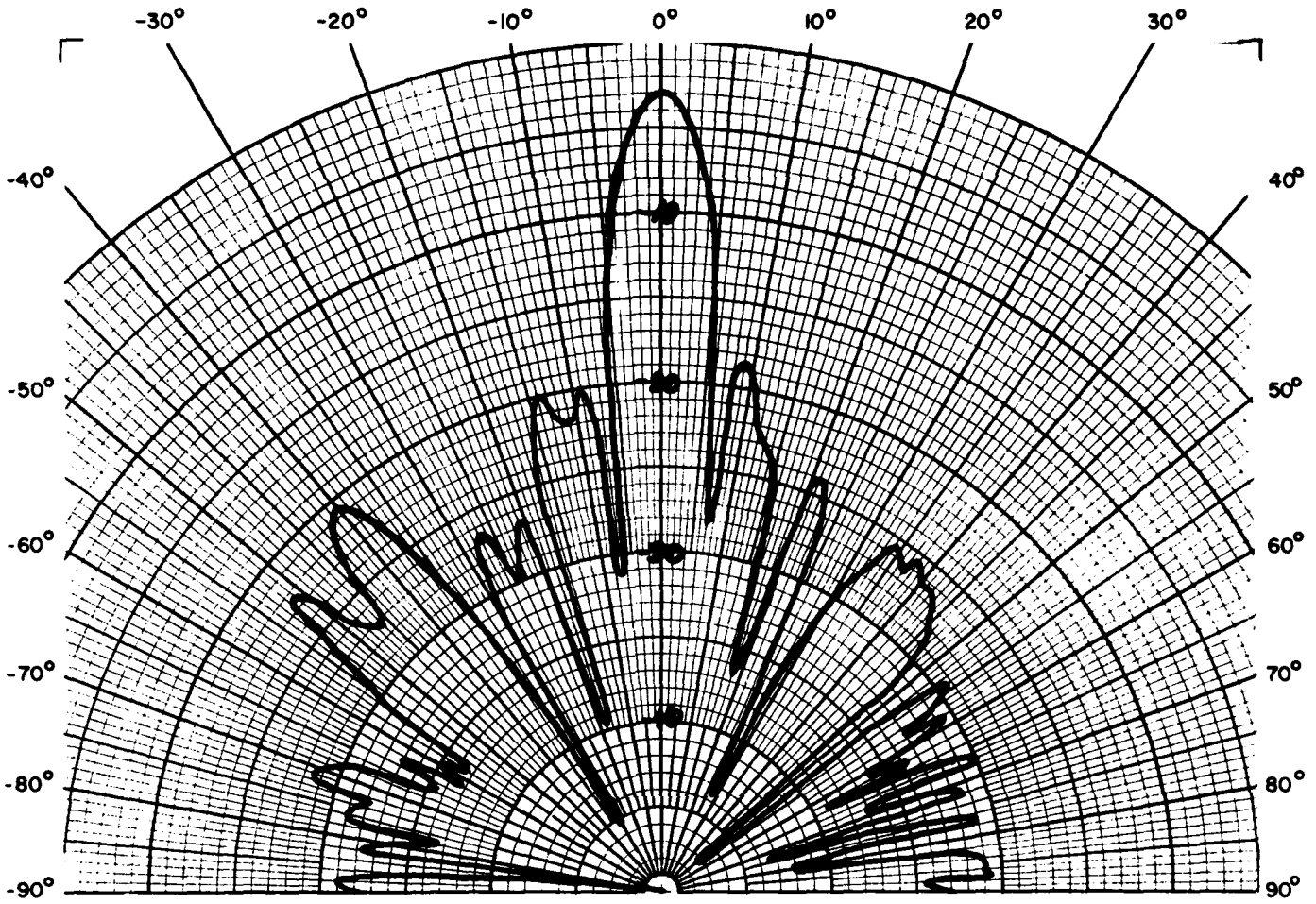
TRACOR, INC DWG A2000-
AUSTIN, TEXAS STR-

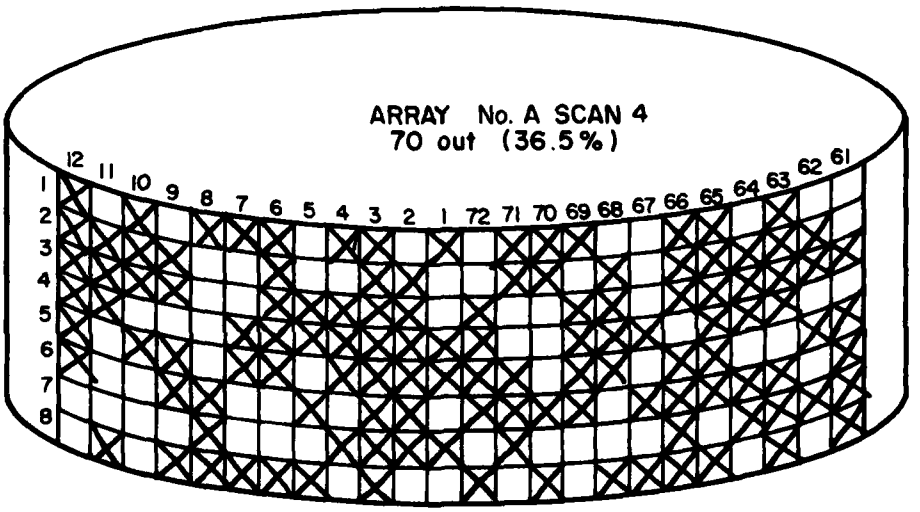




C3

TRACOR, INC. DWG. A2000-
AUSTIN, TEXAS STK-





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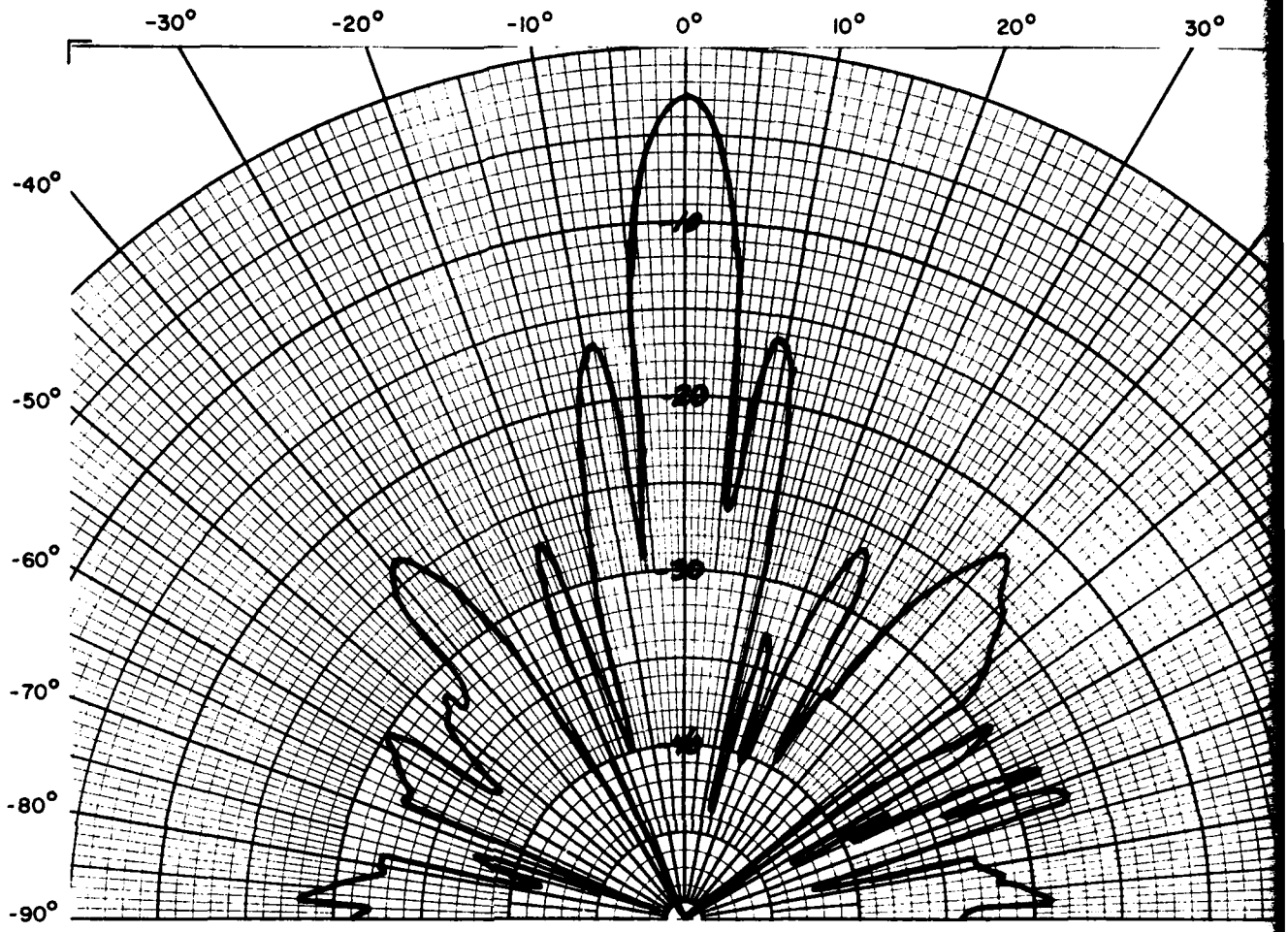
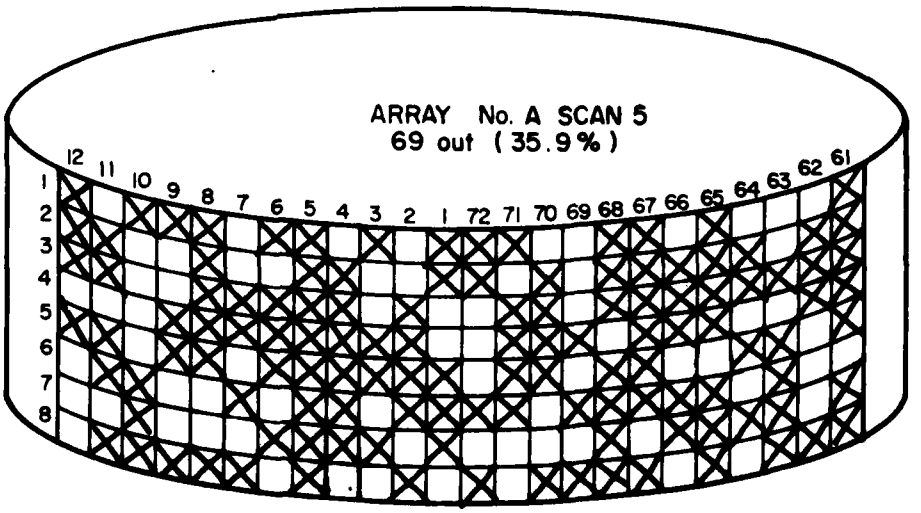
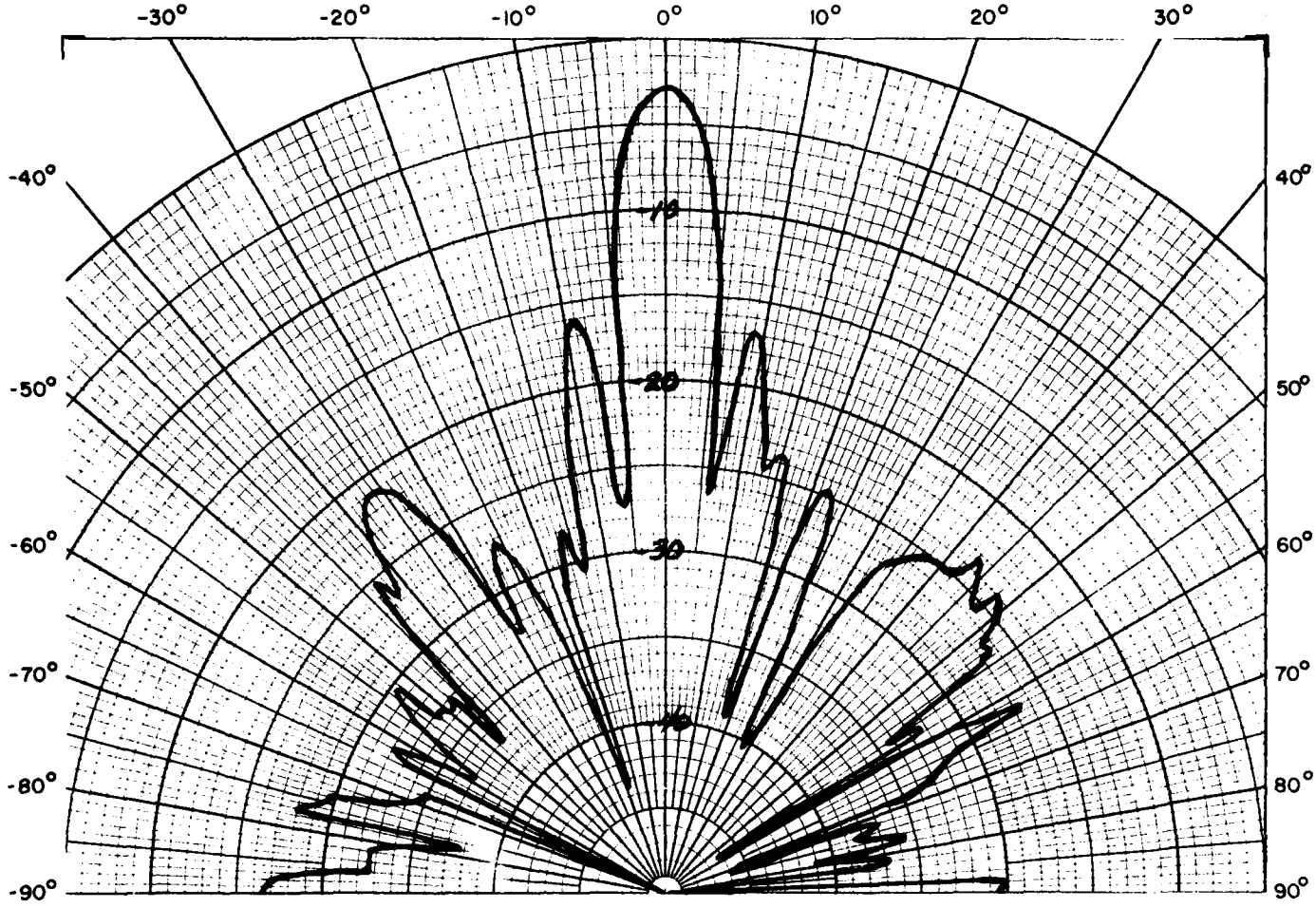
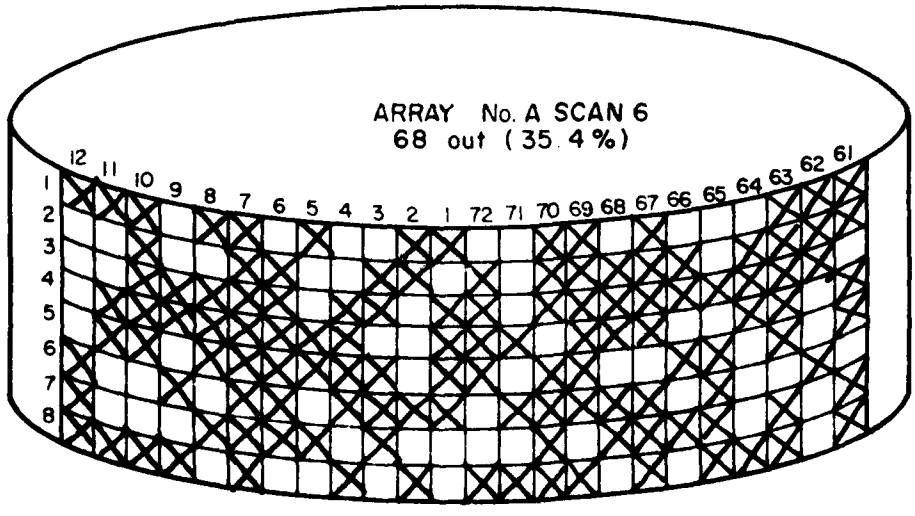
TRACOR, INC. DWG. A2000-
AUSTIN, TEXAS STK-





TRACOR, INC. AUSTIN, TEXAS DWG. A2000-
STK-





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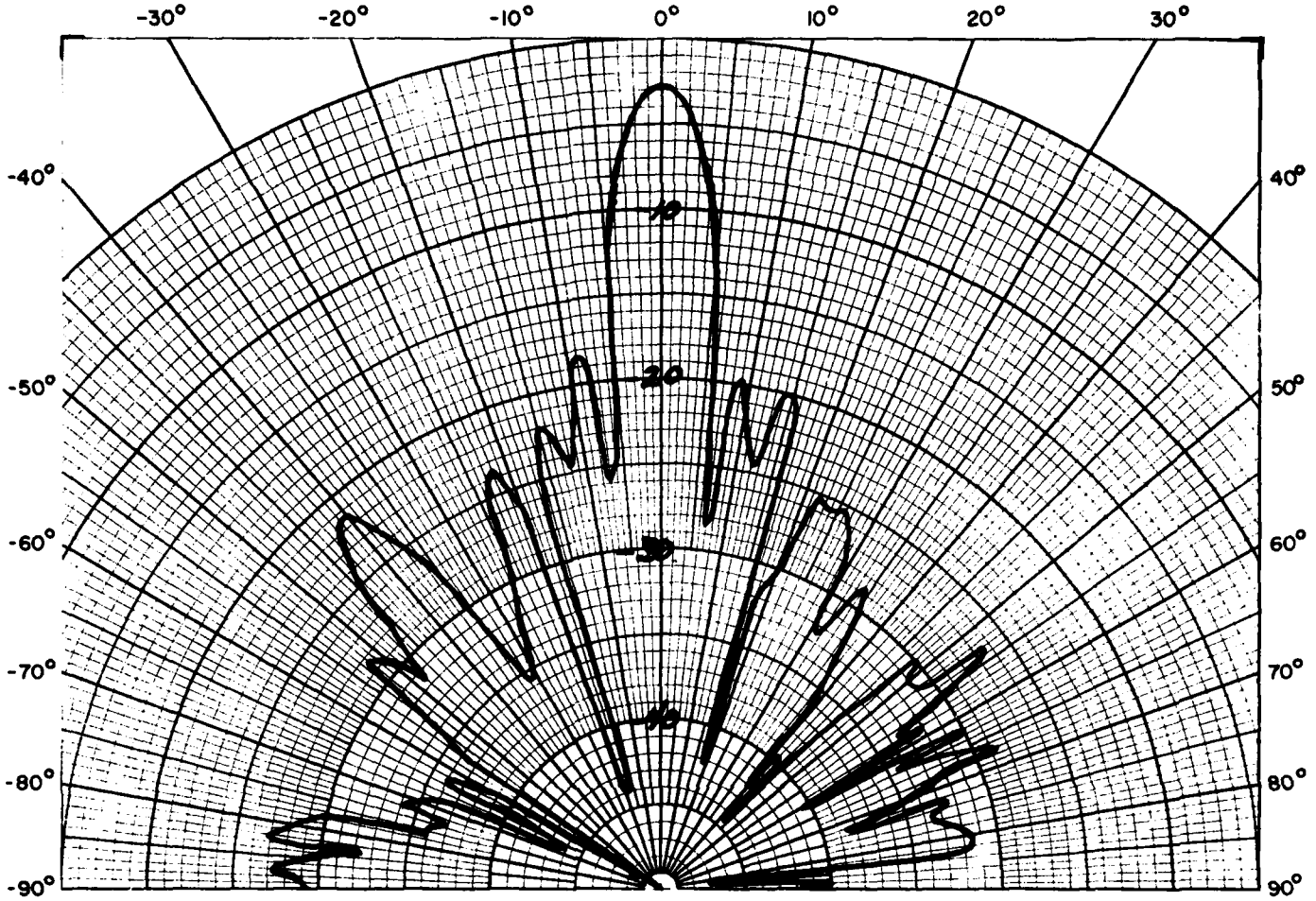
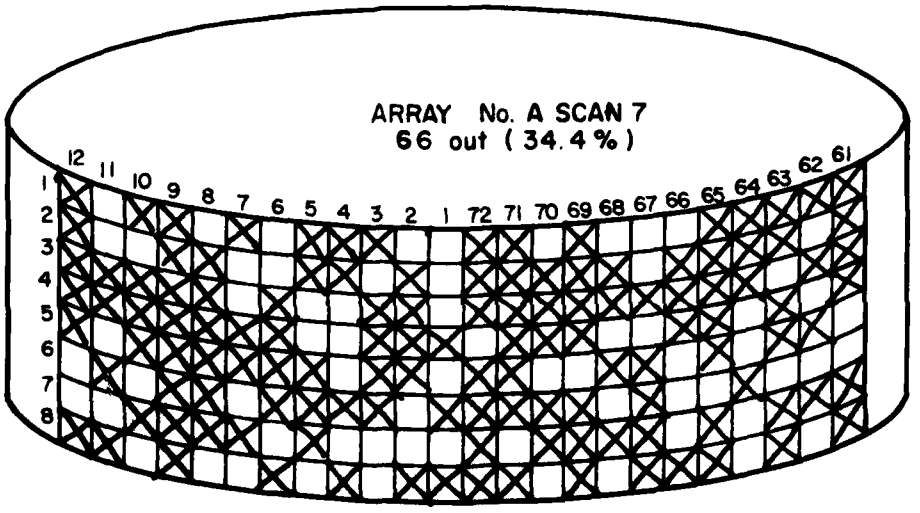
TRACOR, INC. DWG A2000.
AUSTIN, TEXAS GTK·





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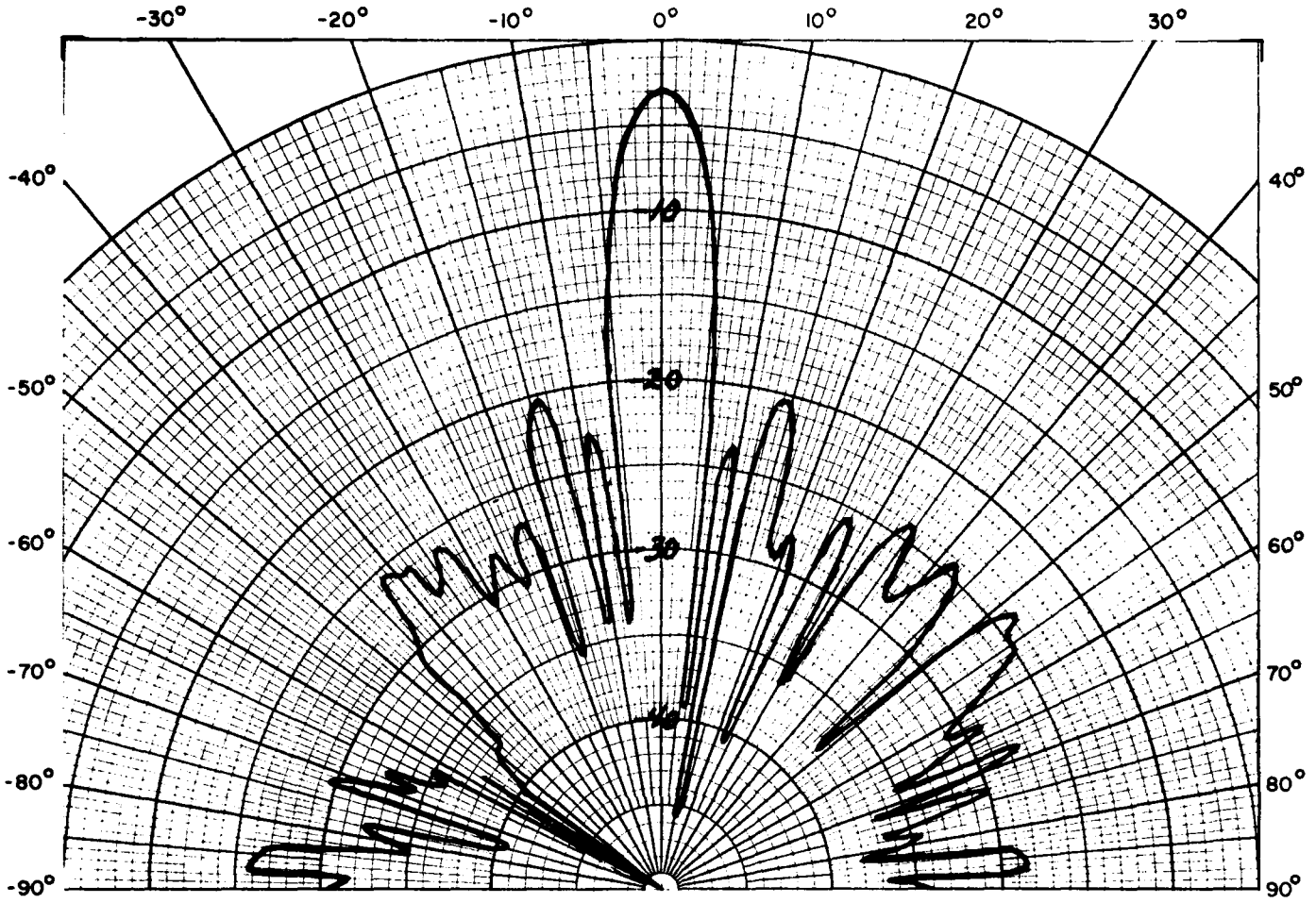
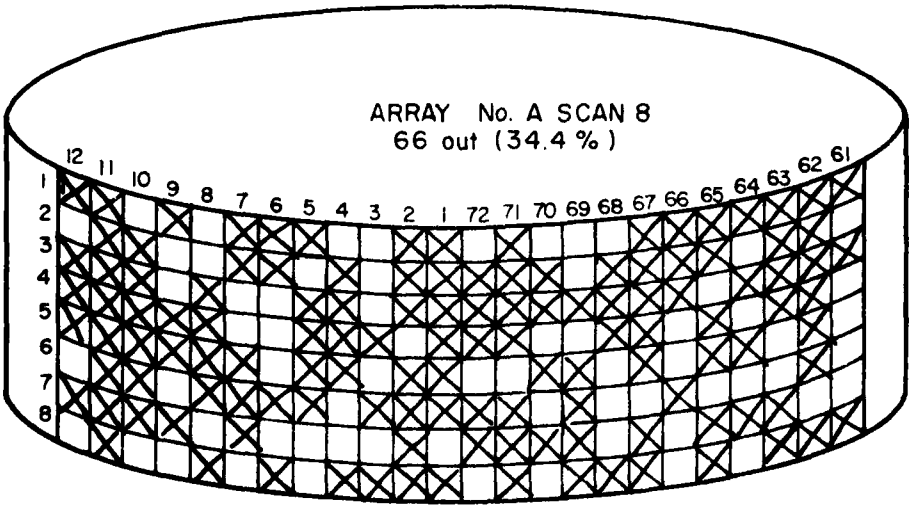
AUSTIN, TEXAS STK-





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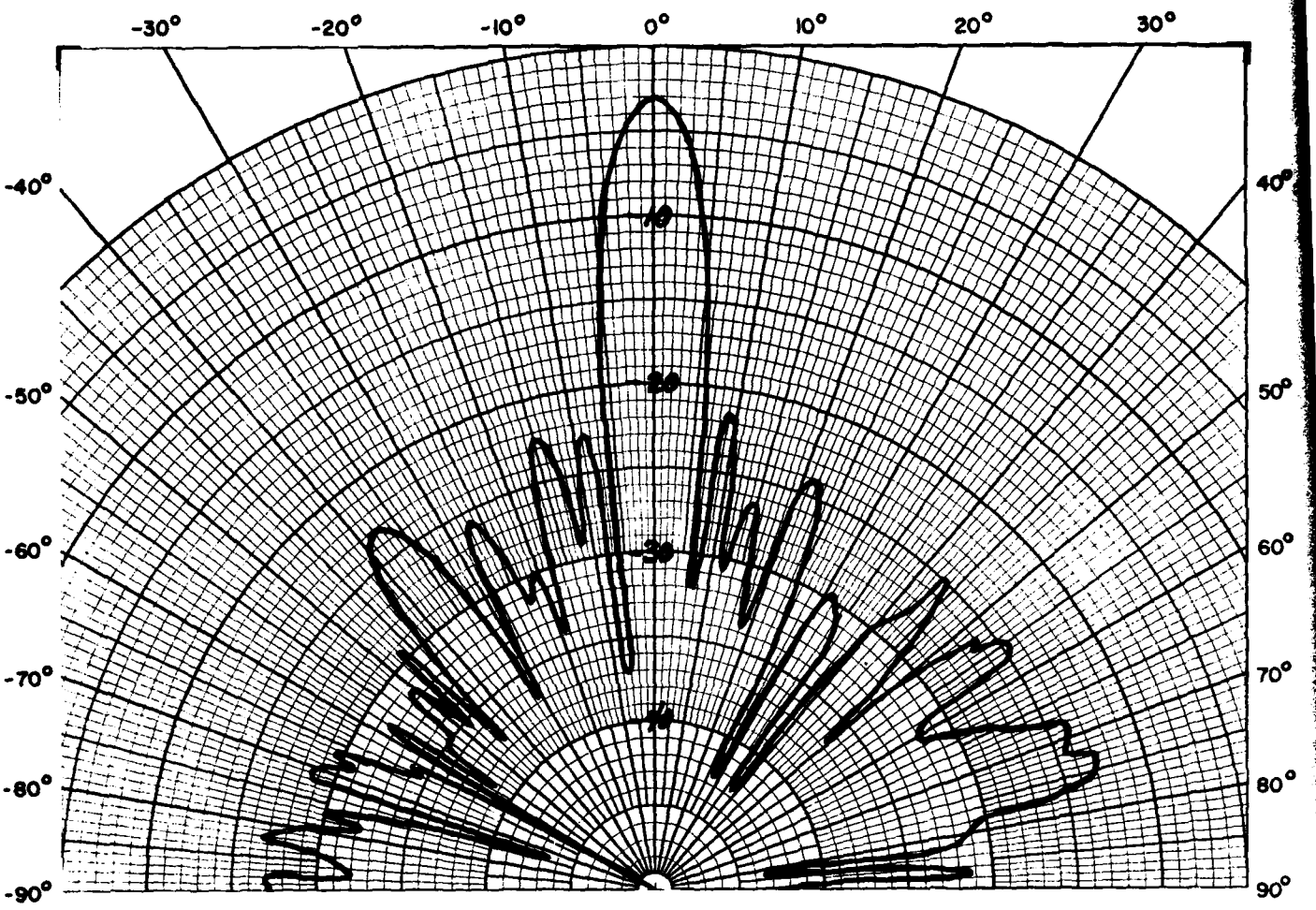
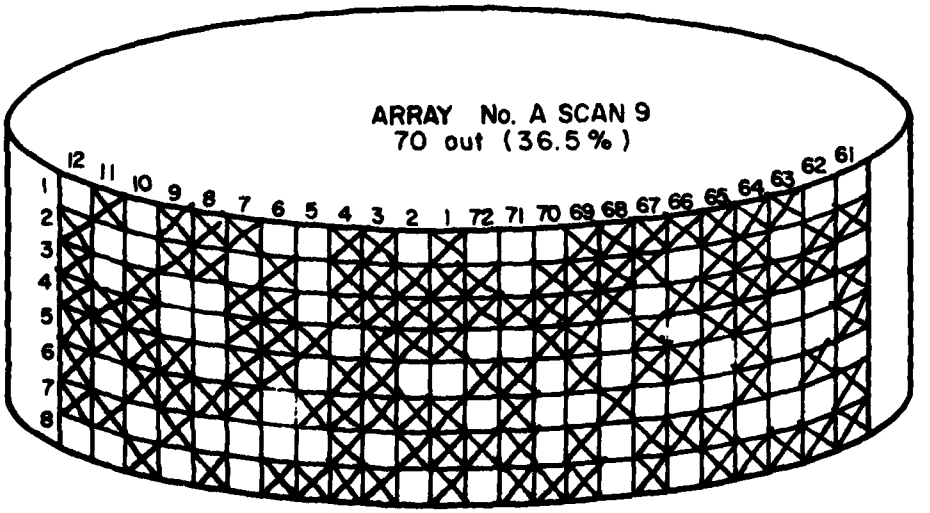
AUSTIN, TEXAS GTK





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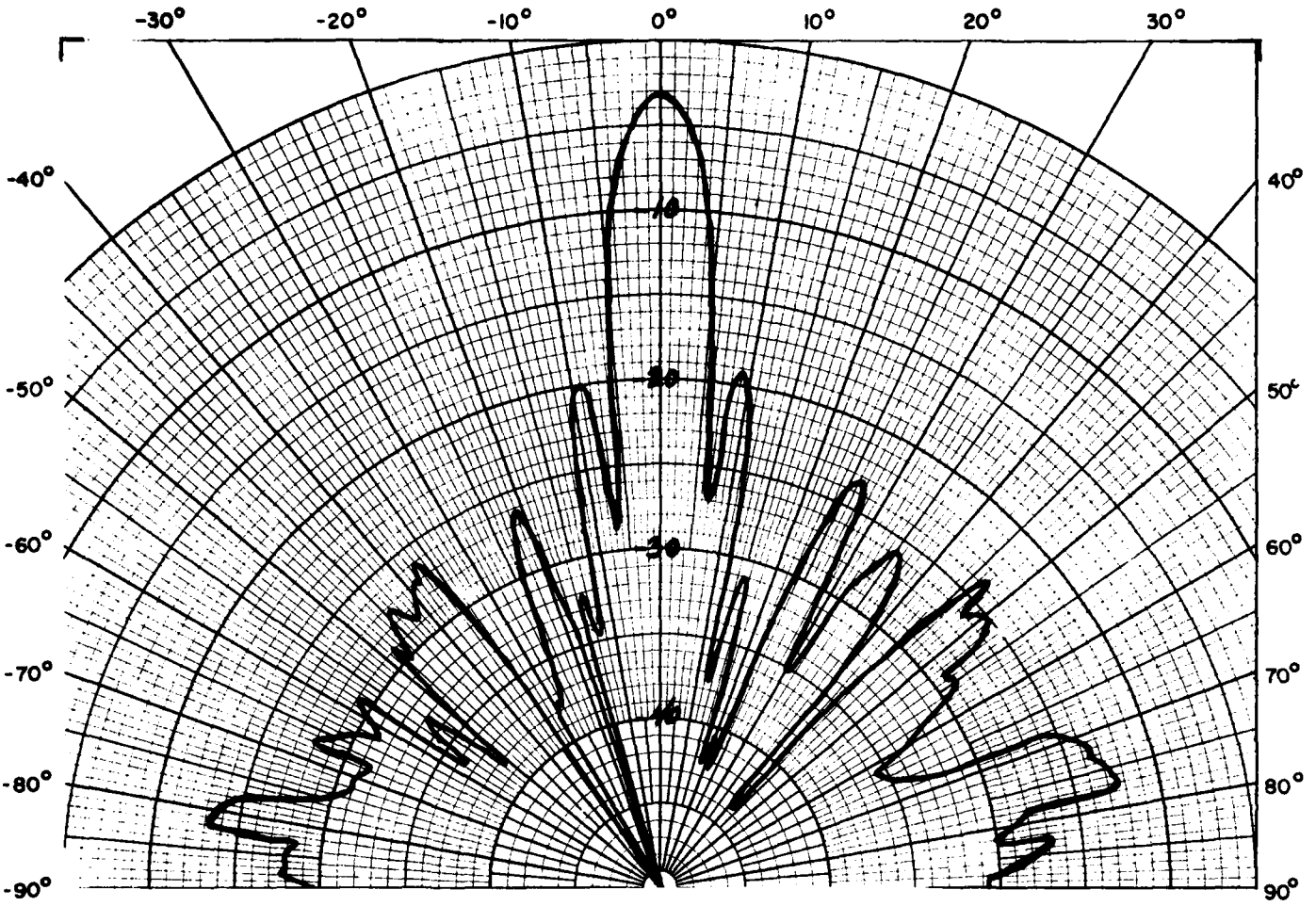
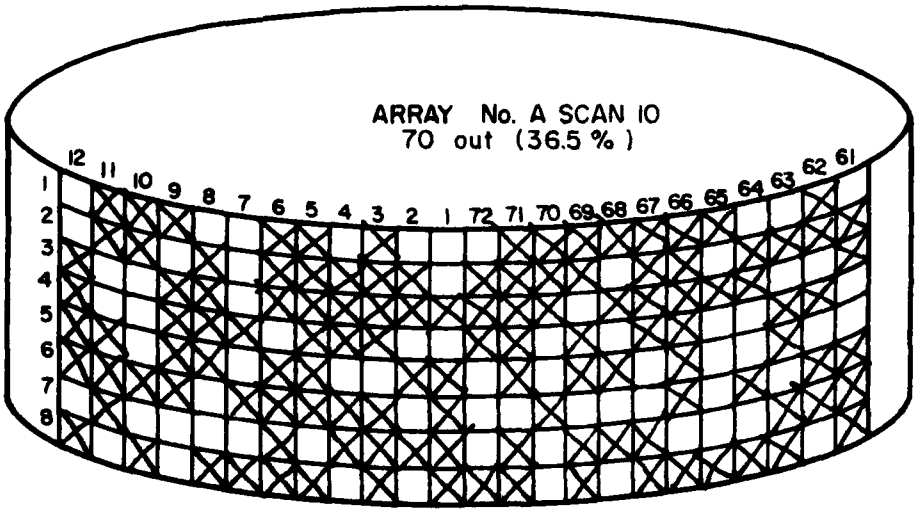
TRACOR, INC. AUSTIN, TEXAS DWG. A2000- STK- JRT 5-1-64





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TRACOR, INC. AUSTIN, TEXAS DWG. A2000-
STK-JRT 5-1-64

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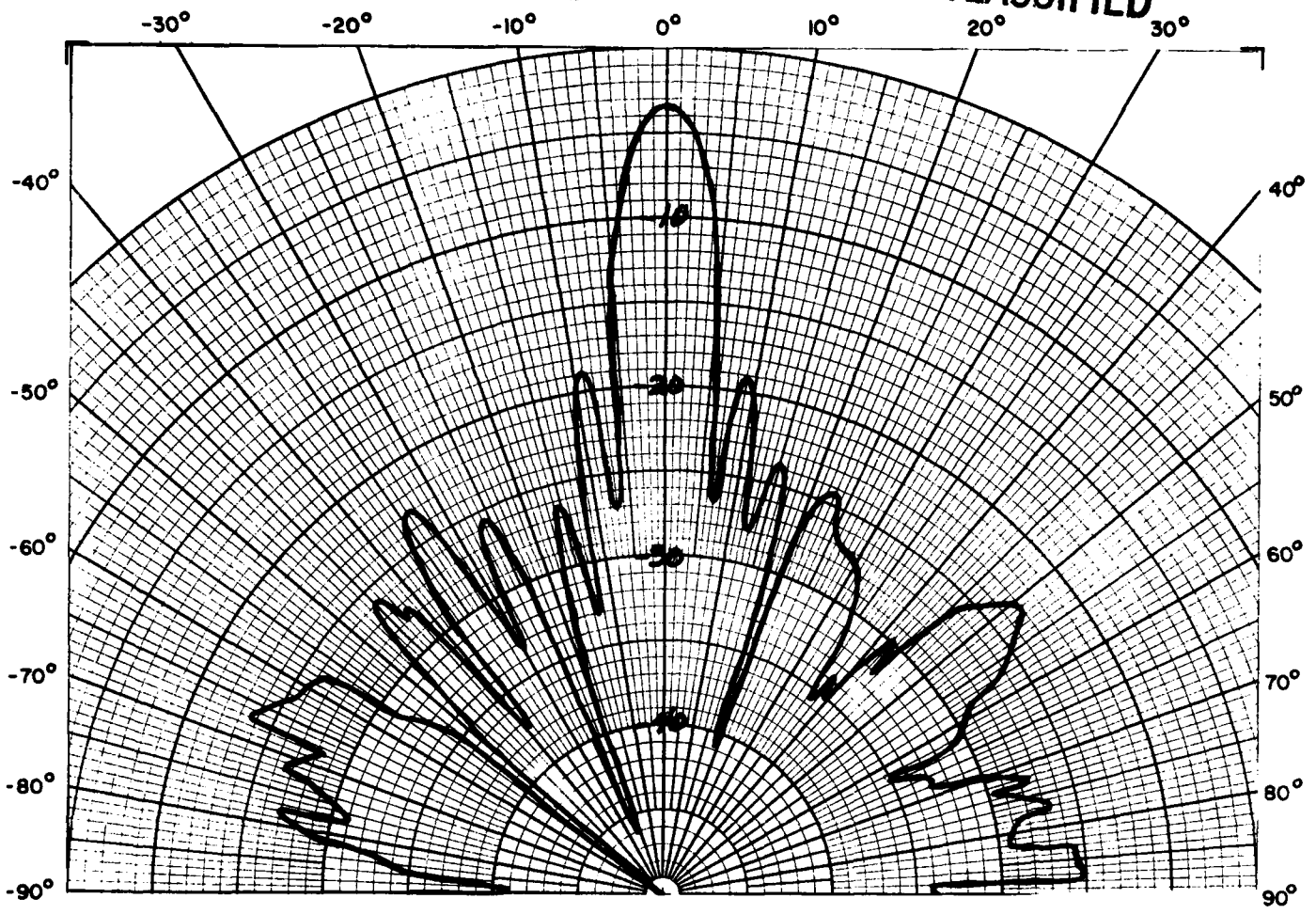
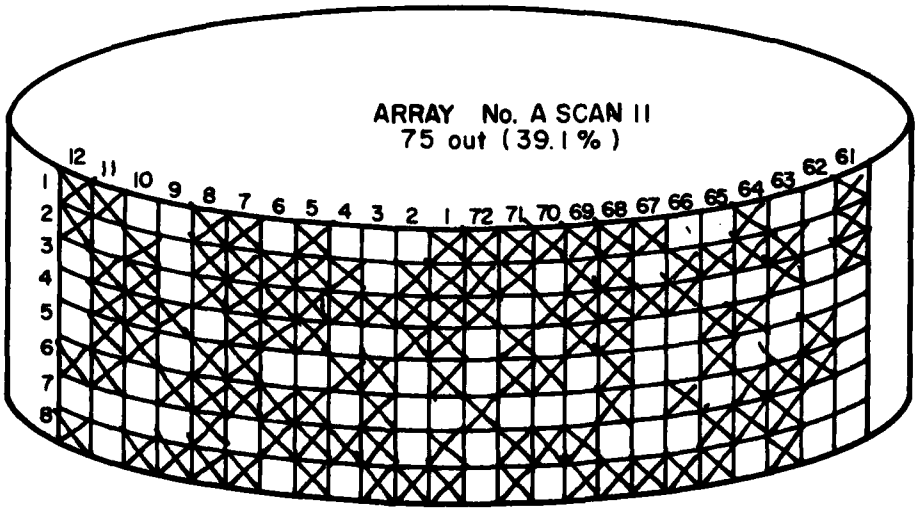
UNCLASSIFIED





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TRACOR, INC. DWG. A2000-
AUSTIN, TEXAS STK-JRT 5-1-64

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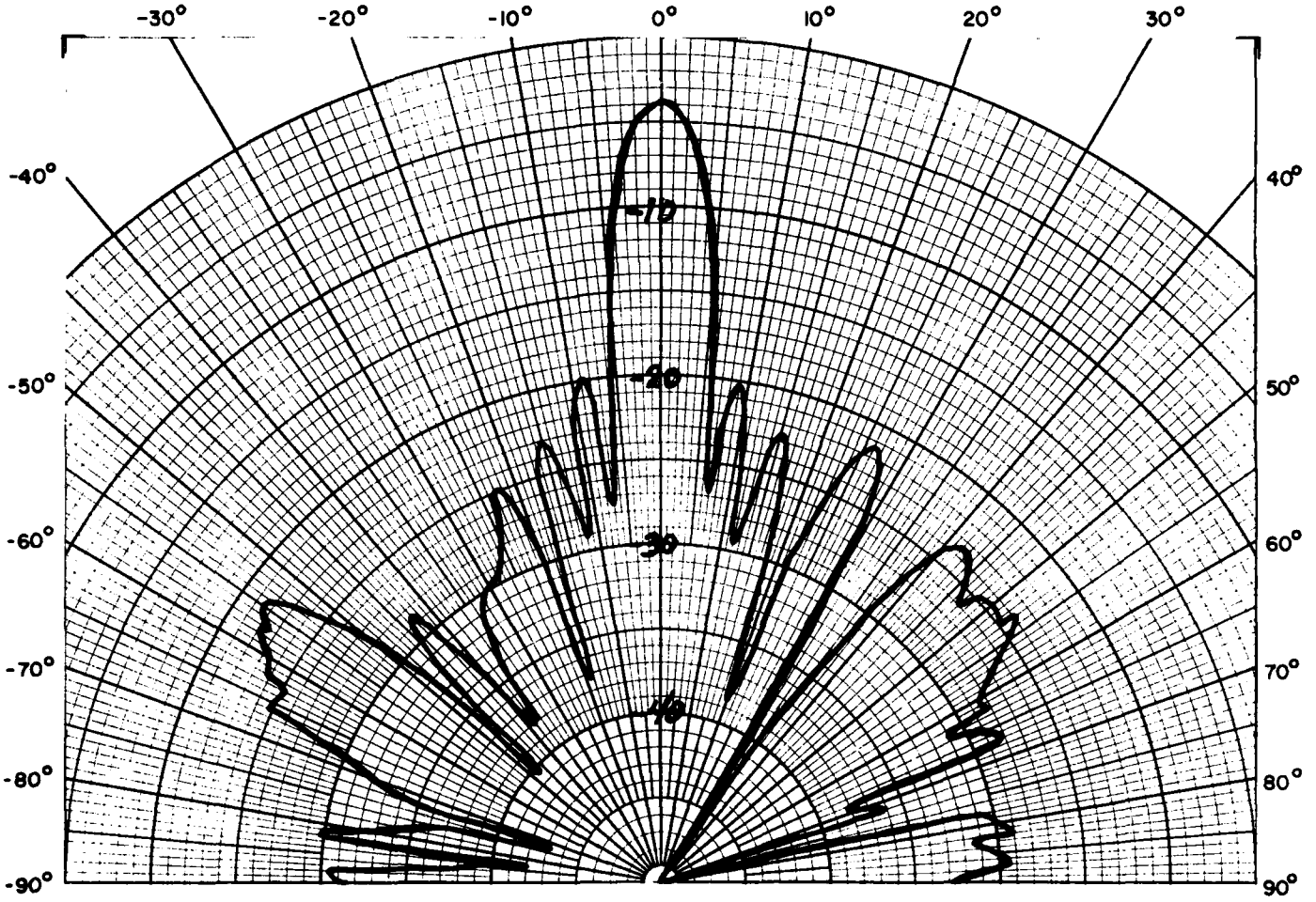

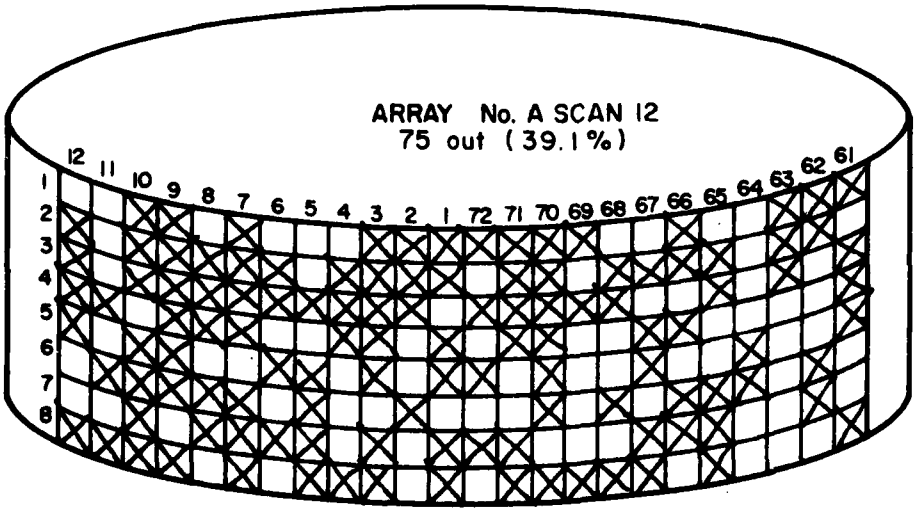

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